FINAL REPORT

PERFORMANCE MEASUREMENT IN PRODUCTION AND SUPPORT AREAS OF A SHIPYARD

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PREFACE

The National Shipbuilding Research Program seeks to improve productivity within the shipbuilding industry. An important part of this Program is conducted by SNAME Ship Production Committee Panel SP-8 on Industrial Engineering.

This project, which resulted from two project proposals presented by SP-8, was funded because it was widely recognized that traditional methods of performance measurement within operations areas of U.S. shipyards are not adequate to support contemporary shipbuilding methodologies and business practices. The purpose of this project was to identify and test some alternative performance measurement methods that might be more appropriate for modem shipbuilding and business operations, and to establish a generic methodology for implementing new performance measurement methods in a shipyard.

This project was conducted by Peterson Builders, Inc. of Sturgeon Bay, WI. Task Director was Mr. Doug Diedrick, Senior Industrial Engineer at PBI. Principal investigation was performed by Mr. Doug Diedrick and Mr. Mark Spicknall, Senior Research Associate with the University of Michigan Transportation Research Institute - Marine Systems Division. The project team would like to thank the many shipyards that participated in the project survey, and would especially like to recognize Jonathan Corporation and Philadelphia Naval Shipyard for their significant contributions to this project. The project team would also like to thank the many people at Peterson Builders, Inc., who participated in performance measurement case studies. The work, under Newport News Purchase Order P2283T-O-N7, began May 1992 and was completed in September 1993.

Shipyard Performance Measurement Final Report

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PERFORMANCE MEASUREMENT IN PRODUCTION AND SUPPORT AREAS OF A SHIPYARD

I. Executive Summary

This project came about as a result of discussions among U.S. shipbuilding executives relating to the inadequacy of the performance measurement methods being. used today in many U.S. shipyards. First, much current performance measurement is based on the principles of financial accounting, which focus primarily on valuing inventory and on high level and short term financial performance, rather than on the customer, on quality, and on long term process improvement and financial health. In addition, many current methods of performance measurement provide performance by ship system rather than by interim product type and work process. Also, much of the data generated by current performance measurement systems is "snapshot" data, which does not facilitate either the implementation or measurement of continuous improvement efforts. It was also identified that some current methods of performance measurement can be "gamed" through the manipulation of labor charging and progressing. Finally, some current measures of cost performance are based on the assumption that direct labor cost is the primary driver of overall cost performance, even as the industry has evolved to become less labor intensive, and even though it has been recognized that the time required from contract award to delivery is a very significant cost driver (not to mention a very visible measure of a company's competitiveness).

The intent of this project was to identify successful methods of performance measurement presently used in shipyards and in other industries, to experiment with some performance measurement methods at Peterson Builders, Inc., and to develop and describe a generic methodology for the implementation of new performance measurement methods in U.S. shipyards.

These are the steps outlined in the **Approach to Implementing New Performance Measures.**

1.	Identify areas of possible need for improved performance measures.
2	Define product and production plan including schedules, budgets, quality requirements, and level of detail necessary.
3.	Examine present methods of performance measurement.
4.	Form team to lead implementation.
5.	Educate team members about performance measurement methods.
6.	Identify specific performance measurement needs.
7.	Identify alternative methods of performance measurement.
8.	Identify capabilities of information system.
9.	Quantify costs of implementation.
10.	Identify and quantify benefits of implementation.

11.	Develop and initiate implementation plan including information system chances, labor reporting chances, etc.
12.	Team collects data, develops reports, and analyzes variances.
13.	Make initial review of system, identify and implement needed chances.
14.	Make performance measurement system part of everyday life including continuing education of potential users and others affected by system.
15.	Maintain regular review of measurement system for continuous improvement.

The approach outlined is intended to be a general guideline for implementing new performance measurement methods. Individual shipyards may wish to modify the implementation process to suit their own needs. However, the importance of education in this process at all levels of the organization can not be underestimated. The more informed all participants and users of performance measurement are, the easier it will be to manage the changes that are inherent and necessary in creating and sustaining an environment of continuous improvement.

II. Introduction

II.A. Purpose

This project, which resulted from two project proposals (8-90-1 and 8-90-2) presented by SP-8, was funded because it was widely recognized that traditional methods of performance measurement within operations areas of U.S. shipyards are not adequate to support contemporary shipbuilding methodologies and business practices. The purpose of this project was to identify and test some alternative performance measurement methods that might be more appropriate for modem shipbuilding and business operations, and to establish a generic methodology for implementing new performance measurement methods in a shipyard.

II.B. Background

Performance measurement is necessary for an organization to determine how well it is meeting externally- and internally-imposed expectations at specific points in time and over long periods of time. Performance measurement can be applied to the overall organization and to organizational subgroups and activities. Indirect measures of performance, such as cost of operations, can be used to identify whether there are problems that need to be identified and addressed, and can also be used to monitor the effects of continuous improvement efforts. Direct performance measurements, such as statistical sampling and analysis of process outputs, can be used for short-term diagnosis and problem solving, and also to help identify long-term trends in process performance.

Traditional performance measurement methods at the operations level of U.S. shipyards have been indirect measures, and have usually provided some kind of cost *and schedule performance* based on budgets and schedules that have been established from past performance, and that are broken down by ship system and trade. Cost and schedule performance variances are usually reported to operations management and personnel in terms of direct labor hours rather than dollars, with the assumption that direct labor is the primary cost driver for shipbuilding operations.

Quality has traditionally been defined as “conformance to specifications, ” with quality performance measurement understood to mean 100 percent inspection of all interim products and systems at several steps in the production process. Processes have been assumed to be adequate, and rework and scrap have been considered part of “normal shipbuilding practice. ”

Traditional methods of performance measurement are still in use in many U.S. shipyards because

- o some shipyard managers are not very familiar with modem shipbuilding methods and quality perspectives, and are simply more comfortable with system-based shipbuilding methods and traditional definitions of quality;

- information generated by new types of performance measurement might threaten the status quo;

- like many other U.S. industries, the performance measurement system is to some extent still driven by the financial accounting requirements of valuing inventories and providing traditional quarterly financial statistics to corporate management and stockholders;

- new methods of performance measurement might require some investment in training and equipment; and

- the major customer of U.S. shipyards, the Navy, is familiar with the financially-based, direct labor-driven, and ship system-oriented information that these methods provide.

Today's state-of-the-art shipbuilding organization is more manufacturing-oriented, with shipbuilding processes defined based upon the principles of Group Technology (GT). These principles dictate that discrete manufacturing, on-unit, on-block, and on-board work processes be defined based on the types of interim products that must be manufactured and assembled to produce a ship. These interim products can be composed of pieces of individual or multiple systems, and can be manufactured and assembled in parallel, and erected nearly complete in a very short period of time.

In a modem shipbuilding environment, budgets and schedules are defined by product type and process, rather than by ship system and trade, and are based on work standards that have been developed for each product-process combination. These product-based budgets and schedules provide meaningful yardsticks against which shipyard operations can measure their cost and schedule performance, as well as their productivity. Interim and final product quality are dependent on work processes being in control so that each process produces interim products that are predictable and acceptable to the next "customer" in the shipbuilding process. Process control is verified through random sampling rather than through 100 percent inspection. The requirements and expectations of each "customer" in the shipbuilding process, as well as those of the final customer, must be defined, and statistical quality/process control (SQC/SPC) and other quality-related problem solving techniques must be learned and used by all employees. Performance measurement in a modern shipbuilding environment is more product-, process-, and customer-oriented, and is part of every employee's daily work, rather than being the responsibility of Quality Assurance, Finance, and Accounting.

II.C. Technical Approach

First, production and support areas in U.S. shipyards that could potentially benefit from improved performance measurement had to be identified and prioritized. This was done through a survey of shipyard executives, managers, and engineers, and through a review of survey results by members of SP-8. Existing methods of performance measurement in production and support areas of shipyards, and in other industries, were then studied. This research included a literature search, on-sight study and interviews at private and Navy shipyards, and numerous discussions with management personnel from other types of manufacturing companies. Some promising methods of performance measurement were developed for trial implementation at Peterson Builders, Inc. (PBI) in the surface preparation and coating (production) area and the material control (support) area. These trial methods were monitored and refined, a general methodology for implementing new performance measurement methods was outlined based on what had been learned at PBI, and this final report was prepared.

II.D. Outline of Tasks

Task 1: Identification of Areas of Highest Potential Benefit- Identified shipbuilding production and support areas that might benefit from improved performance measurement, and prioritized these areas based on their potential for benefit. This task was accomplished through surveys of knowledgeable executives, managers, and engineers in the shipbuilding industry. The results of the survey follow in Section II.E, and complete survey data are provided in Appendix A.

Task 2: Research of Methods Already Used In Shipbuilding- Identified and analyzed performance measurement methods that are being used today in the key production and support areas identified by SP-8 from the data obtained in Task 1. These performance measurement methods were analyzed for effectiveness and usefulness. This task was accomplished through telephone interviews, through on-sight visits at both Navy and private shipyards, and through a literature search of preexisting shipyard performance measurement information. The yards were chosen based on the degree to which they had studied and implemented effective performance measurement methods, as determined from the responses to Task 1, and based on the relevance of pre-existing data.

Task 3: Research of Methods Used Outside of Shipbuilding- Conducted a literature search to identify possible alternative performance measurement methods that are in use outside of the shipbuilding industry. Those methods that showed promise for application in shipbuilding were thoroughly researched through interviews and on-sight visits with representatives of other industries.

Task 4: Development of Methods- Developed promising performance measurement methods identified in Tasks 2 and 3 for application at PBI in the priority areas identified by SP-8. An implementation plan for applying these methods at PBI was developed. Proposed performance measurement methods and implementation plans were reviewed with PBI management for their comments and concurrence. A generic methodology for implementing new performance measurement methods in shipyards was also developed.

Task 5: Application of Methods- Applied the performance measurement methods developed in Task 4 to the blast and paint, and material control areas at PBI. The implementation of these methods began with the education of executives, managers, and workers at PBI. The effectiveness and usefulness of these methods were monitored for the duration of the project, and the methods were refined as necessary to improve the usefulness of the performance information being generated.

Task 6: Reporting- Provided progress reports and presentations to SP-8.

II.E. Shipyard Survey and Results

II.E.1. Shipyard Survey Goals

The project team developed a survey to be completed by U.S. shipyard executives, managers, and engineers. This survey was intended to:

- Prioritize shipbuilding production and support areas based on their potential benefit from improved performance measurement. High priority areas would be considered for further study.

- Identify successful applications of performance measurement in shipbuilding. Shipyards exhibiting performance measurement success would be pursued by the project team for additional information.

- Present an overview of present U.S. shipyard performance measurement methods that can be used by shipyards as a benchmark for future improvement.

II.E.2. Shipyard Performance Measurement Survey

1) How effective and useful are your present performance measurement methods in the following shipbuilding support areas?

Give a score of 1 to 10, with 1 being “completely ineffective and useless, ” 10 being “exceptionally effective and useful, ” and NA being “not applicable to my shipyard. ”

____ Marketing
____ Contracts
____ Human Resources
____ Training
____ Accounting
____ Finance
____ Legal Affairs
____ Design Engineering
____ Production Engineering
____ Production Control
____ Purchasing
____ Material Control
____ Computer/Info. System Support
____ Telecommunications Support
____ Manuf./Indus. Engineering
____ Facilities Engineering
____ Facilities Maintenance
____ Quality Assurance/Control
____ Employee/Labor Relations
____ Public Relations
____ Safety and Health
____ Welding Engineering
____ Cost Engineering
____ Trades Administration
____ Environmental Engineering
____ Printing/Publication Services
____ Production Tool Support
____ Others (Please Identify)

2) How important is the performance of each of these shipbuilding ~~support~~ areas to the overall performance of your shipyard?

Give a score of 1 to 10, with 1 being “not important at all, ” 10 being “vitally important, ” and NA being “not applicable to my shipyard. ”

_ Marketing
_ Contracts
____ Human Resources
____ Training
____ Accounting
____ Finance
____ Legal Affairs
____ Design Engineering
____ Production Engineering
____ Production Control
____ Purchasing
____ Material Control
_ Computer/Info. System Support
____ Telecommunications Support
____ Manuf./Indus. Engineering
____ Facilities Engineering
____ Facilities Maintenance
____ Quality Assurance/Control
____ Employee/Labor Relations
____ Public Relations
____ Safety and Health
____ Welding Engineering
____ Cost Engineering
____ Trades Administration
____ Environmental Engineering
____ Printing/Publication Services
____ Production Tool Support
____ Others (Please Identify)

3) Briefly identify/describe the methods that are used by your shipyard to measure the performance of each shipbuilding support area with a score of 8 or greater in Question 2.

4) Briefly identify/describe the methods that are used by your shipyard to measure overall performance of support areas.

5) How effective and useful are these methods that are used to measure the overall performance of support areas?

6) In general, have the performance measurement methods used in your shipyard's support areas evolved from internal customer needs or external customer requirements?

7) How effective and useful are your present performance measurement methods in the following shipbuilding production areas?

Give a score of 1 to 10, with 1 being "completely ineffective and useless," 10 being "exceptionally effective and useful," and NA being "not applicable to my shipyard."

____ Structural Manuf./Assem.
____ Pipe Manuf./Assem.
____ Sheet Metal Manuf./Assem.
____ Electrical Manuf./Assem.
____ Machine Manuf./Assem.
____ Foundry
____ Surface Prep and Coat (in-shop)
____ On-Unit Work
____ On-Block Work
____ On-Board Work
____ Inspection/Testing
____ Riggers
____ Temporary Services
____ General Cleaning Services
____ Others (Please Identify)

8) How important is the performance of each of these shipyard production areas to the overall performance of your shipyard?

Give a score of 1 to 10, with 1 being "not important at all, " 10 being "vitally important, " and NA being "not applicable to my shipyard. "

____ Structural Manuf./Assem.
____ Pipe Manuf./Assem.
____ Sheet Metal Manuf./Assem.
____ Electrical Manuf./Assem.
____ Machine Manuf./Assem.
____ Foundry
____ Surface Prep and Coat (in-shop)
____ On-Unit Work
____ On-Block Work
____ On-Board Work
____ Inspection/Testing
____ Riggers
____ Temporary Services
____ General Cleaning Services
_ Others (Please Identify)

9) Briefly identify/describe the methods that are used by your shipyard to measure the performance of each shipbuilding production area with a score of 8 or greater in Question (8).

10) Briefly identify/describe the methods that are used by your shipyard to measure overall performance of production areas.

11) How effective and useful are these methods that are used to measure the overall performance of production areas?

12) In general, have the performance measurement methods used in your shipyard's production areas evolved from internal customer needs or external customer requirements?

13) Briefly identify/describe the methods that are used by your shipyard to measure overall shipyard performance.

14) How effective and useful are these methods that are used to measure the overall performance of your shipyard?

15) If internal customer needs are a significant factor underlying <u>any</u> of your performance measurement methods, what formal methods, if any, have been established within your shipyard to identify these internal customer needs?

II.E.3. Survey Results

Support Area	Overall Rank	Wm. Score
Marketing	1	47.9
Training	2	46.9
Purchasing	3	46.8
Safety/Health	4	44.6
Contracts	5	44.3
Labor Relat.	6	42.8
Mat'l. Control	7	42.3
Human Res.	8	41.7
Finance	9	38.8
Facil. Maint.	10	37.8
Accounting	11	37.6
QA/QC	12	37.4
Cost Engin.	13	35.9
Printing/Pub.	14	35.2
Legal Affairs	15	35.0
Welding Eng.	16	34.9
Tool Support	17	34.5
Pub. Relat.	18	34.1
Telecom.Sys.	19	34.0
Design Engin.	20	33.5
Trades Admin.	21	33.1
Man./Ind.Eng.	22	32.5
Facil. Engin.	23	32.3
Prod. Control	24	32.1
Prod. Engin.	25	30.0
Cmptr. Sys.	26	**29.7**
Envir. Engin.	27	**27.9**

Production Area	Overall Rank	WEt. Score
Sheet Metal Manuf.	1	42.2
Temp. Services	2	40.0
Cleaning	3	37.5
Surface Prep/Coat	4	37.4
Elec. Manuf.	5	36.8
On-Unit	6	36.3
Riggers	7	35.6
Inspect., Test	8	34.0
Machine Shop	9	33.2
Pipe Manuf.	10	30.7
Strut.Manuf.	11	28.7
Foundry	12	28.0
On-Block	12	28.0
On-Board	13	24.4

II.E.4. Discussion of Survey Results

The overall ranking of the shipyard production and support areas in Section II.E.3 was established by combining the responses from questions 1 and 7 (effective and useful) with those from questions 2 and 8 (importance). To accomplish this, the averages of the replies for each area in questions 1 and 7 (effective and useful) were first transposed by subtracting them from ten to create "10-Avg." scores (see Appendix A for detailed worksheets). As a result, the shipbuilding areas with the least effective and least useful average performance measurement then had proportionally higher "10-Avg." scores. In other words, a "10-Avg." score of 1 is defined as being "exceptionally effective and useful, " a "10-Avg." score of 10 is defined as being "completely in effective and useless. " These "10-Avg." scores for each area were then multiplied by their associated average importance weights determined from questions 2 and 8, respectively, to create "Wgt. Scores" for each area. The "Wgt. Scores" were then used to rank the specific shipbuilding areas. Therefore, those shipbuilding areas with the highest rankings are areas with poorer performance measurement <u>and</u> areas for which performance is relatively more important to the overall performance of the shipyard.

The survey results are broken down by New Construction yards, Private Repair yards, and Public yards in Appendix A. However, the results for the Public yard and Private Repair yard categories are statistically meaningless because of the small number of these yards that responded.

Individuals responding for some shipyards commented that they could reliably answer questions 2 and 8, but that their present methods of performance measurement were not well enough documented to answer questions 1 and 7. Therefore, for these specific yards there are answers for questions 2 and 8, but not for questions 1 and 7, and the average scores for each shipbuilding area identified in the survey were determined using the number of yards responding to each question for that area, not the total number of yards responding to the survey.

Some yards misinterpreted questions 1 and 7 to mean, "put 'N/A' if you are not measuring performance in this area. " This mistake is apparent because the same yards have answered questions 2 and 8 with numbers for the same areas for which they answered "N/A" in questions 1 and 7. These areas obviously exist in their shipyards, and there is apparently no performance measurement being done in these areas. The wording of questions 1 and 7 should have defined. a score of "1" as "performance measurement is completely ineffective and useless, <u>or nonexistent</u>, " and "N/A" as "this area <u>does not exist</u> in my shipyard. " To correct this problem for these specific shipyards, "N/A" answers for questions 1 and 7 were changed to "1" for those areas where the yards provided numerical answers for questions 2 and 8.

After reviewing the survey results, members of SP-8 decided that the project team should concentrate its case studies in the areas of surface preparation and coating, and material control.

II.E.5. Summary of Answers to Narrative Survey Questions

General Summary:

o Most responding shipyards mentioned that they use some kind of cost schedule control system to measure cost and schedule variances. It appears from the information provided that the initial implementation of these systems was driven by Navy contract requirements. Most shipyards seem only somewhat satisfied with this method of performance measurement because of its focus on past performance, its lack of timeliness, its general presentation as “snapshot” data rather than trend data, and its tendency to foster reactive management.

o Many responding shipyards stated that internal customer requirements were the main drivers of their performance measures, yet most of these yards also stated that there were no formal mechanisms in place at their yards to identify these internal customer requirements.

o There were some responses presenting fundamental misunderstandings of Total Quality Management. One shipyard responded that TQM is important to help trades and departments improve, but that nothing is really measurable. It is not clear how this shipyard will know if its trades and departments are improving if they are not measuring anything.

o There were some responses presenting narrow understandings of performance measurement, with at least two shipyards stating that performance measurement is the measurement of only overall profitability.

o There was a disturbing, and total lack of reference to the use of Statistical Quality Control/Statistical Process Control methods in measuring process performance. In fact, SQC/SPC was never mentioned specifically, and there was only one related reference, which was about measuring the uniform thickness of paint.

See Appendix B for paraphrases of answers provided for each narrative question.

III. Types of Performance Measures

III.A. Types of Data

There are several general types of data that can be used in developing performance measures. Some of these types of data are listed below.

o Variable/Metric Data- Absolute measure of some variable, such as weight, length, cost, etc., for a particular case.

o Categorical/Attribute Data- Measure of whether a particular case has a certain attribute, falls within a specific category, or meets a given specification. For instance, a part with a weight of between zero and 50 lb. might be designated a category 1 part; a part with a weight of between 50 and 100 lb. might be designated a category 2 part, etc. As another example, if a part meets a certain specification, it might be given a categorical data value of zero, and if it does not meet that specification (rejected) it is given a categorical data value of 1.

0 Tally/Count Data- Measure of the number of cases in a category, or the number of cases with or without a specific attribute during a period of time or for an activity; for example, the number of nonconforming parts per week or per a process iteration.

o Transposed or Transformed Data- Data changed by some mathematical or encoding operation(s).

o Surrogate Data- Data related to, and used to represent other data for reasons of simplicity or familiarity. For example, direct labor hours are sometimes used to represent cost.

o Qualitative Data- Nonquantitative information, usually verbal and descriptive.

o Cross-Section Data- A set of data independent of time.

o Time Series Data- A set of data dependent on time.

Certain specific data may actually be representative of several data types. For instance, a tally of rejected parts could be representative of some variable data that was transposed and then compared to some standard as a basis for acceptance or rejection.

III.B. Typical Areas Of Performance Measurement

III.B.1. Cost Measurement

Identifying the cost of operations is important for several reasons. At the corporate level, cost information is required to determine profit or loss. Knowledge of absolute costs is required to value inventory for financial accounting purposes, and to support short-term pricing decisions. At the operations level, absolute product costs and cost variances from budget, standard, or target can be used to identify short-term operations problems. Trends in absolute costs and cost variances can be used to identify improvement or deterioration in process performance over time, and to measure the effects of proactive improvement efforts.

Traditionally in U.S. shipyards, product costing has meant ship-system costing. The cost of a ship system has traditionally been determined by the sum of direct labor, direct material, and overhead costs allocated as a percentage of direct labor charged to that system. Absolute costs and cost variances have traditionally been reported to operations personnel for each ship system in the form of direct labor hours, with the underlying assumption that the cost of direct labor drives all operations cost. This type of cost measurement is deficient in several ways:

- o Reporting cost by ship system is not meaningful to operations management because ship systems as entities are not representative of the interim products that are actually produced in a modern shipbuilding environment. Operations managers can directly control the production of actual interim products and the operation of specific processes, but they cannot directly control the cost of a ship system.

- o Direct labor cost may not necessarily be the primary cost driver for all activities, especially in modem shipyards, where more automated, and fewer labor-intensive production processes are being used. Other cost drivers, such as machine hours, process duration, and shop floor area used may be more representative of total cost, and thus may be more appropriate for allocating indirect costs to products.

- o The emphasis on direct labor as the primary cost driver of operations, and the reporting of cost variances in terms of direct labor hours can mislead managers.into believing that direct labor cost is, in and of itself, the cause of cost problems. In fact, any type of cost measurement, including that of direct labor cost, simply reflects how numerous factors are affecting operations. Some of the factors that might drive up direct labor costs are poor product design, poor production engineering, poor scheduling, poor layout of production processes, or poor training. In fact, most of the factors that have the greatest influence on overall costs of operations are external to production, and are generally controlled by operations preceding production and by management. Therefore, costs can not be reduced to any great extent simply by managers commanding that the work force improve its productivity. To reduce the costs of operations, including direct labor cost, efforts must be made to identify and solve the real problems causing unacceptable cost data.

Meaningful cost measurement requires appropriate definition of work elements. A meaningful work element should be defined to be a particular type of work (problem area) that can be accomplished without significant interference from other work, and without significantly interfering with other work, at a particular place (zone) and time (stage). The execution of a meaningful work element results in a meaningful and measurable output, or interim product. Meaningful cost measurement requires that work elements be defined as described above to reflect the actual outputs (interim products) that are produced within the shipyard, and over which workers and managers have direct control. If the work elements and cost variance reporting do not reflect actual output, management and workers will not be able to react meaningfully to cost variances.

Meaningful cost measurement is also directly dependent upon the establishment of accurate budgets for each work element. These budgets must be based on assessments of work content and other direct resource requirements, and upon the identification and use of appropriate overhead allocation methods. Initially, when proven cost standards are not available, unverified estimates might have to be used; this can result in questionable initial cost measurement information. As feedback comes from operations, these estimates can be revised, and standards can be developed, resulting in more accurate cost measurement information.

Meaningful cost measurement is also directly dependent upon the use of accurate progressing and charging methods. Progressing and charging must be tied directly to work elements, and must not be falsified, or gamed, to result in artificial output. Otherwise, cost variance data will not be very useful for operations management. Also, accurate progressing and charging is essential for establishing accurate cost projections. If work elements have been defined to reflect the actual outputs of production, progressing and charging are likely to be more accurate.

III.B.2. Schedule Measurement

Performance to schedule is important at the overall contract level and at the shop floor level, particularly for those activities that are operations bottlenecks. Along with cost measurements, schedule variances from budget, standard, or target can be used to identify short-term operations problems. Trends in schedule variances can be used to identify improvement or deterioration in process performance over time, and to measure the effects of proactive improvement efforts.

Monitoring schedule compliance at bottlenecks, and focusing on improving the throughput of these activities, will assure overall schedule compliance, and will help reduce all direct and indirect costs that are driven by process time. Monitoring schedule performance of nonbottleneck activities should be a secondary consideration, and is only important if this measurement will help lead to significant process improvements and cost savings. Otherwise, the resources that would be used in measuring the schedule variances of non-bottleneck activities would be much better utilized in measuring and developing ways to improve the throughput of bottleneck activities.

Like cost variances, schedule variances are only indicators of other factors affecting operations, and are not themselves directly actionable by management. A negative schedule variance indicates that additional investigation and analysis is required to identify and solve the problems causing the variance, and to standardize and incorporate the solution into normal business practices so the problem does not occur again.

Like cost measurement, meaningful schedule measurement is also dependent upon having correctly defined work elements and associated schedules, and accurate progressing methods.

III.B.3. Productivity Measurement

Productivity is usually expressed as the amount of output produced for a given input, or, conversely, as the amount of input required to produce a specific output.

Output is defined as a quantifiable amount of work completed, or planned to be completed. Output is usually expressed in terms of some meaningful product and associated quantity, e.g. joint length welded, square feet of surface painted, or number of valves inspected, or in terms of some value of input resources added to a product.

Input is defined as a quantifiable amount of a particular valuable resource that has been consumed, or that is planned to be consumed, in producing an output. Input is usually expressed in terms of some meaningful measure of that particular resource, e.g. labor hours, hours of time, quantity of material, or dollars.

Productivity measured in the short term can be used to help identify potential short term process problems. Productivity measured and tracked over long periods of time can provide a measure of long term process improvement, and can also provide data for developing standards for production planning and bid estimating. A shipyard will usually use a single process to produce a particular type of interim product. As a result, meaningful productivity measures will usually be product- and process-specific within a particular shipyard. Therefore, productivity measures can be used to compare the efficiency of processes that different shipyards might use to produce the same type of product.

For productivity measurements to be meaningful. each measure must be associated with a specific type of output. To accomplish this, work elements must be classified and grouped by type, and then productivity measures must be established for each type of work element. Planning must be flexible to allow redefinition and/or reclassification of work elements as a result of operations feedback that might show that some work elements do not correctly reflect actual output, or that some work elements are classified incorrectly.

At a macro level

- it is not meaningful to combine or compare car ferry Gross Tons (GT)/Dollar with destroyer GT/Dollar because car ferries and destroyers are very different outputs;
- it is meaningful to combine or compare Ferry Hull #1 GT/Dollar with Ferry Hull #2 GT/Dollar, because both outputs are similar ferries;
- it is somewhat meaningful to combine or compare Ferry Compensated Gross Tons (CGT)/Dollar with Fishing Trawler CGT/Dollar. *

At a micro level

- it is not meaningful to combine or compare the productivity of welding with that of painting;
- it is not meaningful to combine or compare the productivity of painting flat plate in an automated plate painting facility with that of manually painting stiffened bulkheads in a crowded machinery space;
- it is meaningful to combine or compare the productivity of unrestricted vertical welding of a particular type joint and material on one block with that of unrestricted vertical welding of the same type joint and material on another block.

Productivity measurement is also dependent upon accurate definitions of work elements, budgets, and schedules, and on accurate charging and progressing.

111.B.4. **Quality Measurement**

Ultimately, quality is the measure of customer satisfaction. A shipbuilder has external customers who purchase and use the shipyard's final products, and internal customers who utilize interim products and services that are produced by internal and external suppliers. The needs of both external and internal customers are important. High quality products and interim products are defined as those that meet or exceed all customer specifications, requirements, needs, wants, desires, and expectations.

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* Compensated Gross Tons (CGT) are determined by multiplying a ship type-specific factor to the actual gross tons of the ship. The CGT factors have been developed to reflect the complexity of each ship type, resulting in CGT measurements that can be used to compare the productivity of shipyards building different types of ships. The measures usually used are the inverse of productivity, $/CGT or Labor Hours/CGT, so that the resulting numbers are of a magnitude that is more useful. When using CGT factors, it is still important to compare ships of similar size. See "Corporate Performance Measurement. "

A customer, either external or internal, usually provides some specifications and expresses other requirements, needs, wants, desires, and expectations both quantitative and qualitative. To assure customer satisfaction, an organization must use this information to identify what each customer really wants.

Even though specifications are usually expressed quantitatively, they may not clearly reflect what the customer really expects. For example, a specification might call for 20 roils of paint thickness on the outside of a hull. The customer might expect every point measured to be exactly 20 roils thick, 95% of measurements to be 20 roils plus or minus 3 mils, 99.5% of measurements to be greater than 20 roils thick, 67% of all measurements between 20 roils and 25 roils, or some other variation.

Customer requirements and expectations, which are expressed outside of the specifications, are more often expressed qualitatively and, thus, are even more difficult to define clearly and to quantify. However, if an organization wants to produce a high quality product or service, it must take the initiative to clearly define, in quantitative terms, not only what the specifications say, but also what the customer really expects.

After defining what the customer really wants, an organization must (1) identify the specific product or service characteristics that relate to the customer's requirements, (2) identify the work processes associated with the creation of these product or service characteristics, (3) identify the work process characteristics that must be controlled to assure that the product or service meets the customer's requirements, and (4) define process control methods and measurements required to control these vital work process characteristics.

When a clear specification has been provided by the customer, the customer has usually already carried out step (1). For example, a customer may specify a certain minimum surface finish for a machined part. In this instance, it is a fairly straightforward matter to identify the machining process that creates the surface finish, and the process characteristics (in this case, machine settings) that must be controlled to assure that the required surface finish is produced. The control methods may range from providing adequate training and instructions (including clear communication of required process settings) to the machine operator, to implementing statistical quality control (SQC) to assure that this process remains in statistical control, to implementing specific final inspection procedures.

When all customer requirements are not clearly specified, the identification of customer requirements and steps (1) through (4) above can be accomplished in a much more methodical way using a process called Quality Function Deployment (QFD). The QFD methodology was developed by Kobe shipyard in the early 1970s specifically to help identify customer requirements, and to facilitate customer-driven and concurrent product and process development. The QFD methodology has proved to be so useful that some form of the methodology has been adopted by most world-class manufacturing and service organizations. The National Shipbuilding Research Program has funded the development and presentation of QFD workshops for the U.S. shipbuilding industry. The workshop material can be obtained, and workshop presentations can be arranged, through the NSRP Documentation Center at the University of Michigan.

Types of quality measurements can include simple attribute measurements, SQC control charts, ratios of rejects versus total inspected, and quality-related costs. If training is vital to maintaining control of a particular process, the number of process-specific training hours per month might be an important quality measurement. If specific process settings, such as travel speed for a welding machine, are vital to process and quality control, a simple process-setting checklist for the operator might be a useful quality measurement tool. Going through a QFD-type exercise might reveal that product or service delivery conformance to schedule is a very important "quality" for the customer, in which case existing schedule variance measurements might also be considered quality measurements. Essentially, the types of quality/process control measures required are determined on a process-by-process basis.

One type of quality measurement method, which is useful for monitoring the overall progress of quality initiatives and also for justifying quality improvement efforts to management, is called *cost of quality* measurement. Cost of quality measurement uses existing cost data, and estimates from each activity or department the percentage of their resources that are used specifically for prevention, appraisal, response to failures internal to the company, and response to failures external to the company. Cost of quality measurement provides only an approximation of the company's quality-related costs because the method accounts for only those costs that are most easily and directly identified as quality-related. Indirect costs related to quality, such as the cost of lost goodwill and sales due to an external product failure, are usually not accounted for using this method. This is due to the difficulty and cost that would be associated with identifying these costs accurately. Following is a list of various types of prevention, appraisal, internal failure, and external failure costs.

PREVENTION COSTS
Quality Engineering
Receiving Inspection
Equipment Maintenance
Some Percentage of Manufacturing Engineering
Some Percentage of Design Engineering
Quality Training
Some Percentage of Marketing and Marketing Research
Customer/User Perception Surveys/Clinics
Contract/Document Review
Some Percentage of Product/Service/Design Development
Design Quality Progress Reviews
Some Percentage of Design Support Activities
Product Design Qualification Test

Service Design and Qualification
Field Training
Purchasing Prevention Costs
Supplier Reviews and Rating
Purchase Order Tech Data Reviews
Supplier Quality Planning
Operations (Manufacturing of Service) Prevention Costs
Operations Process Validation
Operations Quality Planning
Design and Development of Quality Measurement and Control Equipment
Operations Support Quality Planning
Operator Quality Education
Operator SPC/Process Control
Quality Administration
Some Percentage of Administrative Salaries
Some Percentage of Administrative Expenses
Quality Program Planning
Quality Performance Reporting
Quality Education and Training
Quality Improvement
Quality System Audits

APPRAISAL COST
Laboratory Analysis
Some Percentage of Design Analysis
Final Product Acceptance Inspection
Interim Product Inspection
Purchasing Appraisal Costs
Receiving or Incoming Inspections and Tests
Measurement Equipment
Qualification of Supplier Product
Operations Appraisal Costs
Planned Operations Inspections, Tests, and Audits
Checking Labor
Product of Service Quality Audits
Inspection and Test Materials
Set-up For Inspections and Tests
Special Tests (Manufacturing)
Process Control Measurements
Laboratory Support
Measurement Equipment
Depreciation Expenses for Test Equipment
Maintenance and Calibration Labor
Outside Endorsements and Certifications
External Appraisal Costs

Field Performance Evaluation
Special Product Evaluations
Evaluation of Field Stock and Spare Parts
Review of Test and Inspection Data
Miscellaneous Other Quality Evaluations

INTERNAL FAILURE COSTS
Quality-Related Scrap (not Designed Scrap)
Operations Rework and Repair Costs
Some Percentage of Manufacturing/Process Engineering
Product/Semite Design Internal Failure Costs
Design Corrective Action
Rework Due to Design Changes
Scrap Due to Design Changes
Production Liaison Costs
Purchasing Failure Costs
Purchased Material Reject Disposition Costs
Purchased Material Replacement Costs
Supplier Corrective Action
Rework of Supplier Rejects
Uncontrolled Material Losses
Operations Failure Costs
Material Review and Corrective Action Costs
Disposition Costs
Troubleshooting or Failure Analysis Costs (Operations)
Investigation Support Costs
Reinspection/Retest Costs
Extra Operations
Sales Losses Resulting From Sale of Downgraded Product or Service
Internal Failure Labor Losses
Unscheduled Downtime

EXTERNAL FAILURE COSTS
Net Returned Bad Material Cost
Some Percentage of Marketing
Some Percentage of Manufacturing/Process Engineering
Repair of Sold Products
Complaint Investigations
Retrofit Costs
Recall Costs
Warranty Claims
Liability Costs
Penalties
Lost Customer/User Goodwill (significant indirect cost difficult to estimate)
Lost Sales (significant indirect cost difficult to estimate)

Prevention, appraisal, internal failure, external failure, and total quality costs are monitored relative to output/sales over time to identify if the overall costs associated with quality are decreasing. There is nothing wrong with the costs of prevention and appraisal increasing, as long as the internal and external failure costs decrease enough to provide total quality cost improvement. Quality cost data can be used to justify total quality programs by comparing the percentage that sales would have to increase to gain the same increase in net profit as a certain percentage reduction in total quality cost. In companies that have not implemented successful total quality improvement programs, it is not unusual for a significant amount of their total expenses to be directly and easily identifiable as quality-related costs. For some of these companies, reducing quality-related costs by half would have the same effect on net profit as doubling sales.

In summary, quality performance measurement is any measurement meant to establish how well the final customer, and customers internal to the company, are being satisfied.

III.B.5. Innovation Measurement

Competitive companies have the capability to improve their existing products continually, and to learn quickly and act to create new products in response to new customer demands. A few examples of measures that companies use to determine their level of innovation follow.

- Trends and rates of improvement in process productivity, cost, schedule, and quality (on-time delivery, defect rates, yield, etc.)
- Development time for new products, from concept to market, versus that of their competitors
- Percent of sales from new products
- Number of patents received

III.B.6. Financial Measurement

The important measures of financial performance should be as forward-looking as possible. A company must have adequate cash flow to support operations, so cash flow measurement and projection is important in the short term. However, the goal of a company should be to grow and become more profitable in the long term. Some financial measures that help identify long term health are growth of sales, growth of operating income, increased market share, and increased return on equity. These types of measures have obvious value for upper management and stockholders. But some companies have found that providing this type of information, along with balance sheets, to operations management and personnel on a regular basis, and providing the training necessary to understand this information, has resulted in significant improvements in operations.

IV. Present Shipyard Performance Measurement Methods

IV.A. Cost and Schedule Measurement

A large number of shipyards responded in the project survey that they were utilizing costischedule control systems (CSCS, CS^2, etc.) to measure their cost and schedule performance. Following is an explanation of how cost schedule control systems work.

o Absolute Cost Variance = Earned Output-Actual Cost = BCWP-ACWP
o Percent Cost Variance = (Earned Output-Actual Cost)/Earned Output
= (BCWP-ACWP)/BCWP
o Absolute Schedule Variance = Earned Output-Planned Output = BCWP-BCWS
o Percent Schedule Variance = (Earned Output-Planned Output) /Planned Output
= (BCWP-BCWS)/BCWS

ACTUAL COST represents the amount of an input/resource (usually labor hours or dollars) consumed to date in the creation of a specific output. For many cost and schedule measurement and control systems, Actual Cost is called Actual Cost of Work Performed, or ACWP.

EARNED OUTPUT represents the amount of work that has actually been completed to date, and equals percent progress multiplied by planned output. Although Earned Output can be expressed in terms of some product and associated quantity actually completed (e.g. joint length welded, square feet of surface painted, number of valves inspected), for CSCS it is expressed in terms of the budget earned (actual "value added") to date. For CSCS, Earned Output is called Budgeted Cost of Work Performed, or BCWP.

PLANNED OUTPUT represents the amount of work planned to be completed at a specific point in time. Planned Output can be expressed in terms of some quantity of a meaningful product expected to be completed, for example joint length welded, square feet of surface painted, or number of valves inspected. However, for CSCS it is expressed in the same units as the planned input, for example labor hours or dollars expected to be required to produce the specified output (planned value added). In this form, planned output is representative of the cumulative input budget, in labor hours or dollars, and is called Budgeted Cost of Work Scheduled, or BCWS.

Traditionally, ACWP, BCWP, and BCWS are plotted over time, and cost and schedule variances are kept tabularly, as shown in Figure 1.

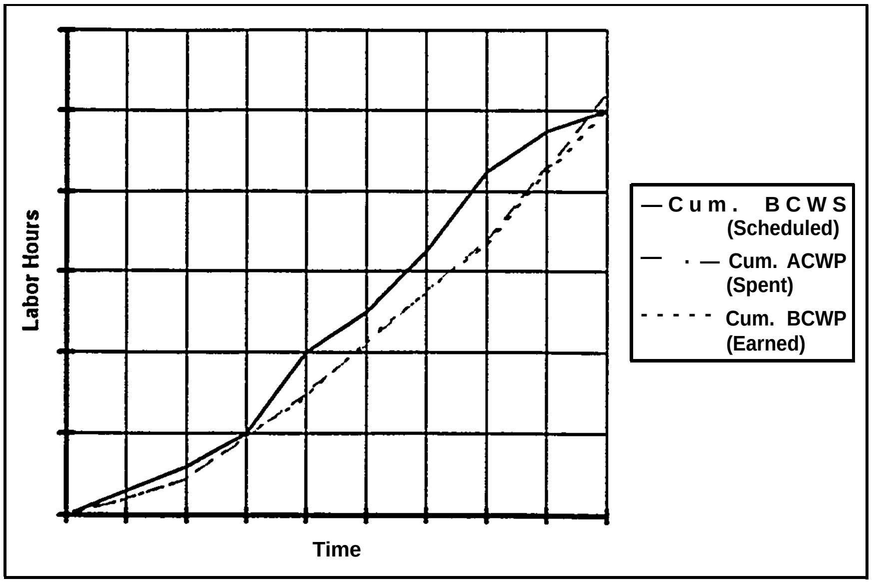


Figure 1
Traditional CSCS Data Representation

Meaningful and useful cost and schedule measurement is dependent upon

o definition of product- and process-based work elements/interim products,
o definition of accurate budgets for each interim product,
o definition of accurate schedules,
o accurate progressing, and
o accurate cost collection or charging.

If any one of these elements is not present, cost and schedule measurements are likely to be meaningless for operations. Unfortunately, it is apparent that many U.S. shipyards still define their work elements using a ship system-based work breakdown structure (SWBS) rather than a product-based work breakdown structure (PWBS). This could be because they always have, and because some of the Navy's cost and schedule reporting requirements dictate the use of SWBS. It is very difficult to accurately budget, schedule, and progress a ship system, because a ship system is not an actual entity that people work with in the shipyard. As a result, the cost and schedule variance information generated by such a CSCS system would probably not be very accurate. Even if it were accurate, the information created by such a system would relate to ship systems rather than to interim products and processes, making this information essentially useless for management at the operations level.

Jonathan Corporation, in Norfolk, VA, has gone a long way toward breaking out of the S WBS mold, even while doing work exclusively for the Navy. Their management information system, which they call the Engineered Management System, has allowed them to define interim product-based work elements that can be made up of pieces of several systems, if necessary, while still accumulating the system-based data required by the Navy. Jonathan's planning personnel define work elements with an average direct labor hour content of 20-25 hours, and a maximum limit of 64 labor hours, although they sometimes exceed this limit. A work package is then made up of *30* to 50 work elements, and scheduling is done at the work package level.

Direct labor is charged at the work element level. Because Jonathan's work elements are relatively small, management can maintain accurate progress without worrying about progressing work in process; each work element is either not started or in process with an assumed progress of O%, or closed with an assumed progress of 100%. When a work element is closed, the budgeted labor hours for that element are earned. The system is updated daily, and the data available to management lags real time by one or two days. Cost variances are reported by work element, work package, and trade. Schedule variances are reported at the work package level.

Jonathan's management stated that they had a difficult time convincing the Navy that the extra cost associated with this level of detailed planning would be beneficial. As they have accumulated data, however, they have been able to improve the accuracy of their bids and reduce planning costs through the use of interim product-based planning standards. Jonathan's management agreed that the accuracy of cost collection is very important to achieving accurate cost and schedule variances, and stated that keeping personnel charging their time accurately requires constant management attention, particularly with the large number of work elements that might be open at any given time in their system.

Jonathan's system does a good job of providing timely (but not quite real time) cost and schedule variance data by product and process. However, their system presents these data in reports filled with tables of numbers that can be difficult to sift through. The data are also "snapshot" data; the system provides no cost and schedule variance trends over time, either tabularly or graphically. This type of snapshot data presentation can influence management to focus primarily on short-term "fire fighting" rather than on long-term process improvement. Also, the absolute and variance data provided at the operations level are given in direct labor hours rather than dollars. The assumption is being made that direct labor hours are the primary cost driver of operations, which might be a reasonably valid assumption for the complex naval overhaul work that Jonathan does.

Pearl Harbor Naval Shipyard has developed better ways to present CSCS data through its TQM efforts. They use graphic displays of the variances around axes representing "on time" and "on budget. " Pearl Harbor Naval Shipyard also tracks cumulative cost and schedule variances over time to identify trends better. To verify and control the accuracy of their CSCS data, they also track charging and progressing accuracy over time. It is an important evolution to get beyond "snap shot" data to look at trends; a shipyard that watches trends in operations is beginning to establish tools that will help support an environment of continuous improvement.

Some examples of alternative presentations of CSCS data are shown in Figures 2 and 3.

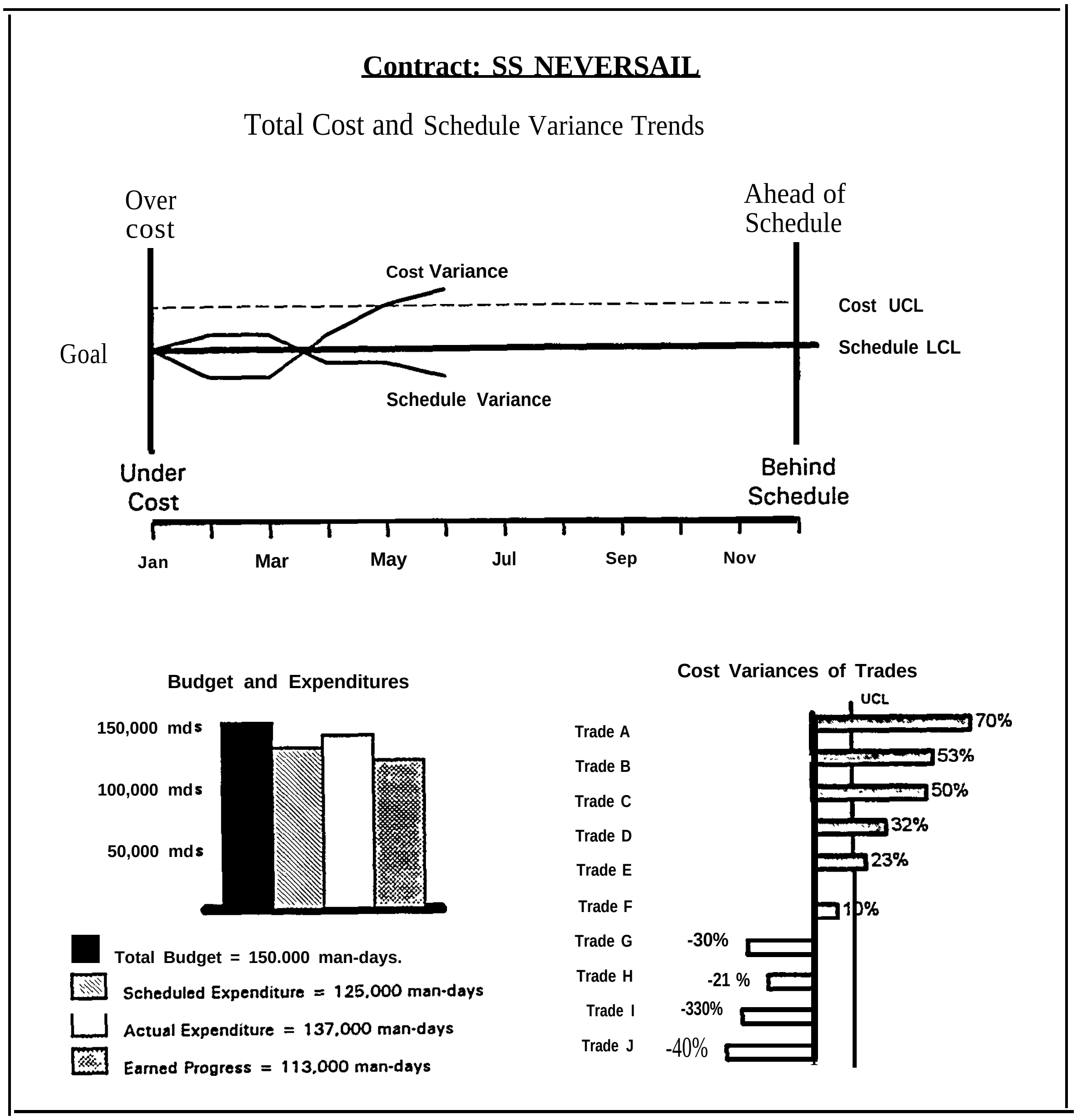


Figure 2
Sample Cost and Schedule Variance Presentations

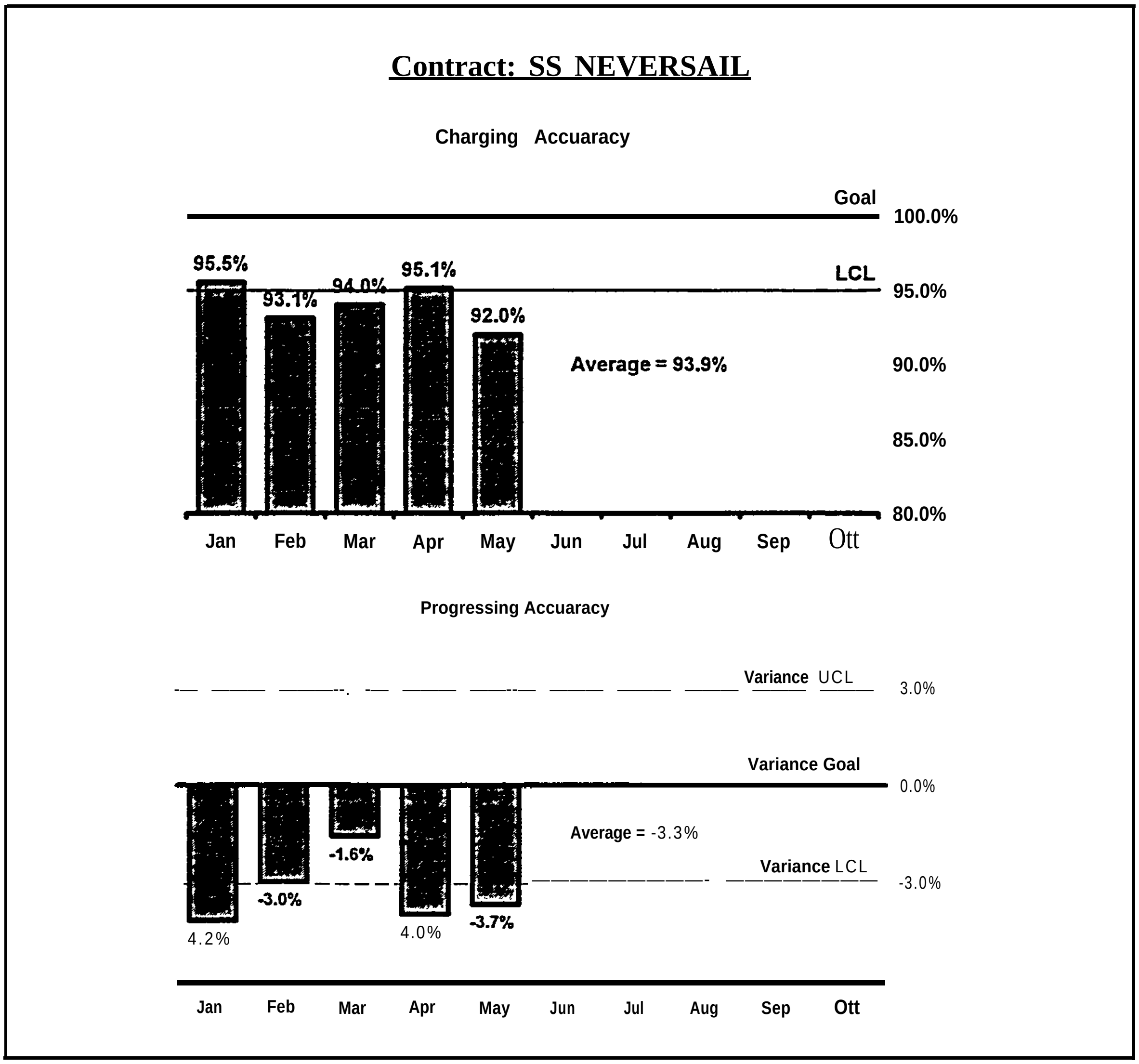


Figure 3
Sample Charging and Progressing Accuracy Presentations

IV.B. Quality Measurement

Interestingly, U.S. naval shipyards seem to be further along in the implementation of TQM initiatives than private U.S. shipyards. This is probably due to general Department of Defense (DOD) pressure to reduce costs, and more specifically due to naval shipyards needing significant improvements in performance in order to justify their survival. For whatever reasons, the naval shipyards seem to have made some significant progress in defining, and attempting to meet, external and internal customer requirements, beyond mere specifications.

Along with Pearl Harbor Naval Shipyard, Philadelphia Naval Shipyard has taken great strides in the area of quality measurement. Philadelphia Naval Shipyard measures reject rates for pipe welding (see Figure 4), hull structural welding, socket welding, foundry heats, material receipt, and other processes. [1]

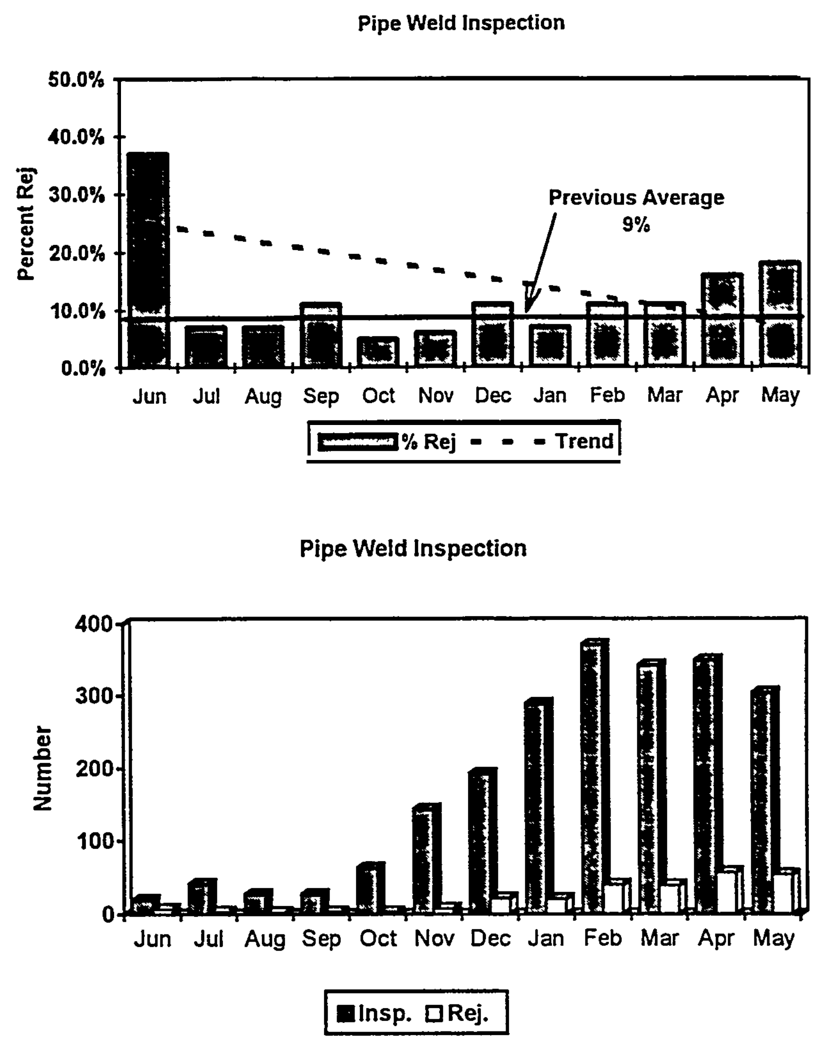


Figure 4
Philadelphia Naval Shipyard's Weld Inspection Measurements

Philadelphia Naval Shipyard measures material receipt to schedule (see Figure *5)*, and in-process cost variances and schedule variances.[2] Philadelphia Naval Shipyard's "material dues measurement" is used for early identification of material problems, with the solid bars indicating the number of line items with required delivery dates past due or due within 120 days, the asterisks and connecting line indicating the number of "material dues" with estimated delivery dates later than required delivery dates, and the cross-hatched bar indicating the number of "material dues" that are assigned to completed or canceled work orders. Material inspection operations were identified as a significant bottleneck. The materials inspection measurement graph (see

Figure 5) categorizes material as not yet received in shipyard, received but not on-site for inspection, inspection backlog, and lost. All material requiring inspection for work packages that are late to start, or-that are due to start within 75 days, me measured.

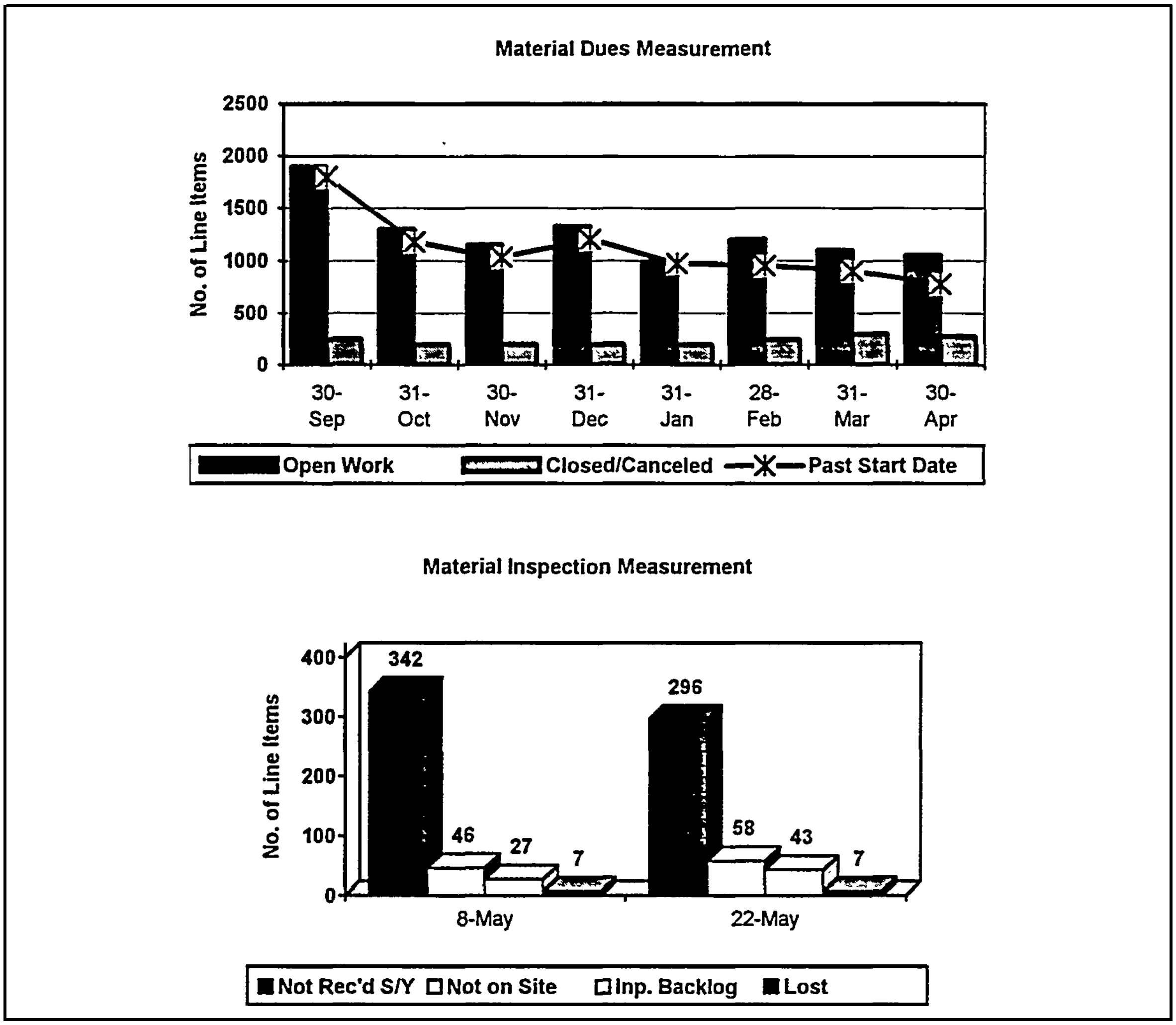


Figure 5
Philadelphia Naval Shipyard's Material Dues and Inspection Measurements

Philadelphia Naval Shipyard's presentation of CSCS cost and schedule data, however, is traditional in the serise that there is one graph with the BCWS, BCWP, and ACV/P curves, and a tabular presentations of variance data. The general approach at Philadelphia Naval Shipyard is to measure and analyze anything that might possibly be of value in solving a particular problem. If a particular measurement does not prove valuable, it is no longer used, and something new is tried.

Very few shipyards responding to the survey, or visited as part of this project, showed evidence of the use of statistical quality control (SQC; also called statistical process control, SPC) to measure and control production processes. In fact, in a recent NSRP study of process accuracy in North American shipyards, only eight shipyards responded to the project survey with any kind of data. and only two of these shipyards showed evidence of using statistical methods to produce and analyze their process data. It is clear that, in general, U.S. shipyards are significantly behind foreign shipyards and other manufacturing organizations in the implementation of SQC/SPC methods.

IV.C. **Productivity Measurement**

All shipyards that are currently producing large commercial ships, or that are seriously considering entering the commercial shipbuilding market, have attempted to determine their own overall productivity, and that of their competitors, in terms of the present sales value per ship, in dollars, per compensated gross ton ($/CGT). A ship's present sales value is the true present value of the purchase cost for the owner, including the effects of resource costs, financial arrangements and subsidies, which vary from yard to yard. Compensated gross tons are used to correct for the different ship types being built at various shipyards. Compensated gross ton coefficients are updated regularly by, and can be obtained from, the Organization for Economic Cooperation and Development (OECD), Council for Shipbuilding, Working Party No. 6. If a yard is concerned only with a single specific ship type, and is only anticipating competing against those yards that are already building this type of ship, then they need only concern themselves with dollars per gross tons ($/GT).

Another way that shipyards can look at this same type of productivity information was presented by Mr. George Bruce at the 1992 NSRP Ship Production Symposium.[3] This method utilizes a plot of some productivity factor relating an input to an output, such as employee-years per CGT, plotted against average fully burdened cost of the input, (in this case, fully burdened average shipyard cost per employee-year) (see Figure 6). This type of plot is generated using data from competitive shipbuilders, and represents a curve of constant cost per CGT for various costs of the input resource identified.

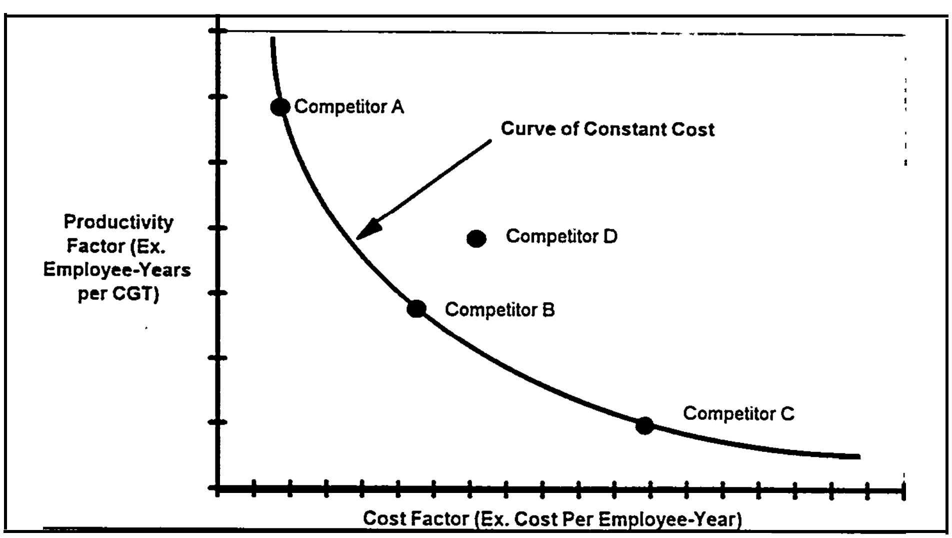


Figure 6
Productivity Cost Curve

The curve of constanst cost passing through points representing shipyards A, B, and C demonstrates that, with everything else being equal, a yard with an expensive resource relative to its competitors would have to use less of that resource for the same output to remain cost competitive. However, this representation of relative competitiveness is limited in that it assumes that the relative value of other important resources is constant for all yards. Therefore, this representation cannot show the total cost trade-offs associated with using multiple resources of varying value --such as labor, time, capital equipment, raw material, shop floor space, and dry dock-- at different relative levels to achieve the same output. For instance, even though shipyard D may not be utilizing its employees as efficiently as the other yards relative to their cost, it may still be able to compete on cost because other resources may be less expensive for them than for their competitors, or they may be using other resources more efficiently.

At the operations level, many shipyards have well established interim product standards, process lanes, and productivity targets for each interim product type. These interim product productivity targets are usually expressed in terms of the amount of specific resources (labor hours, time, etc.) required to produce a type of interim product, or a certain weight of the interim product, such as five labor hours per ton for standard flat panel assembly on a panel line. While these types of productivity measures are only partial productivity measures, in that they measure output relative to only a single input, they do provide a reasonable basis for performance measurement and process improvement, if the input chosen is the most important cost driver in the production process.

In 1982 Avondale Shipyards published a large amount of material related to its reorganization and establishment of interim products, process lanes, and productivity targets. Most of this material can be found in the NSRP Documents 0137-0139, *Manufacturing Technology For Shipbuilding.*[4] Following is a data table (Table 1) and a graph (Figure 7) used by Avondale at that time to measure productivity, which they called "efficiency," and total labor hour expenditure.

Table 1
Avondale's Efficiency and Labor Hour Expenditure Data

	Period Actuals			Estimated-Closed W.O.			Actuals-Closed W.O.		
Date	Cmplt Ton	Labor Spent	Eff. Hr/Tn	Cmplt Ton	Labor Spent	Eff. Hr/Tn	Cmplt Ton	Labor Spent	Et'i'. Hr/Tn
7/16	204	2142	10.50	204	2044	10.02	204	2142	10.50
7/23	600	6300	10.50	804	8056	10.02	804	8442	10.50
7/30	100	869	8.69	904	9083	10.03	904	9311	10.30
8/6	548	5645	10.30	1452	14607	10.06	1452	14956	10.30
8/13	370	3811	10.30	1822	18366	10.08	1822	18767	10.30
8/20	158	1429	9.04	1980	19978	10.09	1980	20196	10.20
8/27	60	612	10.20	2040	20584	10.09	2040	20808	10.20
9/3	304	3030	9.97	2344	23604	10.07	2344	23838	10.17
9/10	354	3547	10.02	2698	27250	10.10	2698	27385	10.15
9/17	232	2062	8.88	2930	29622	10.11	2930	29447	10.05
9/24	286	2391	8.36	3216	32546	10.12	3216	31838	9.90
10/1	228	2085	9.14	3444	34888	10.13	3444	33923	9.85

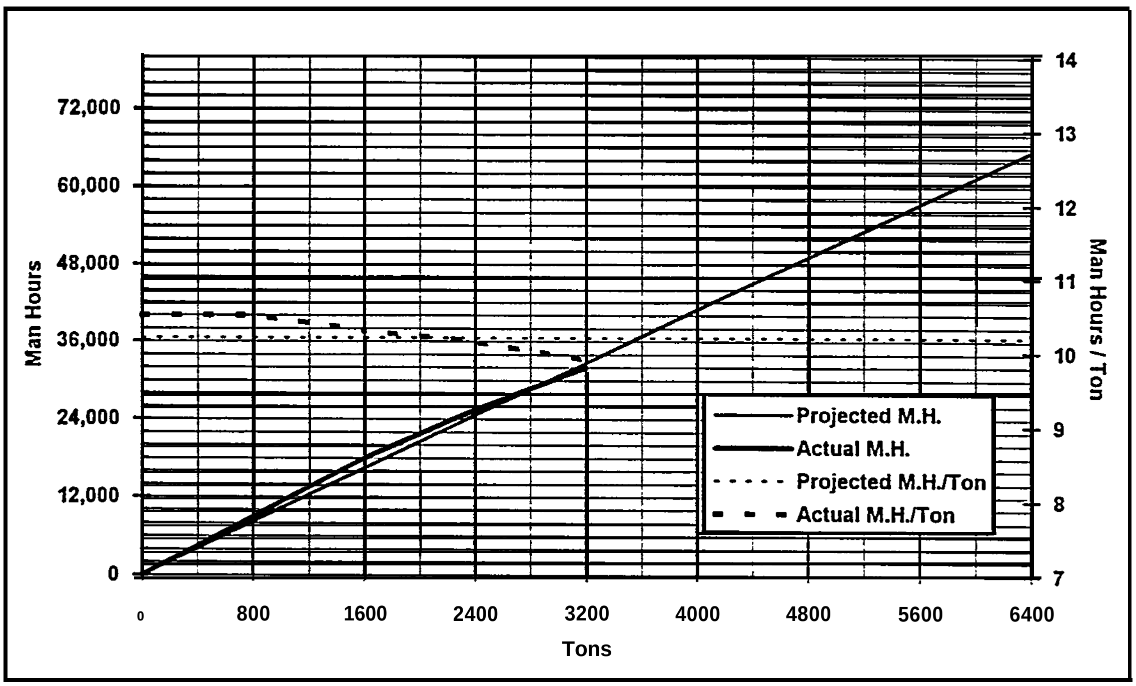


Figure 7
Avondale's Efficiency and Labor Hour Expenditure Graph

V. Performance Measurement Methods In Other Industries

Following are some general and specific examples of performance measurement methods being used in other industries that were thought to be of interest to shipbuilders. The following discussions focus on individual performance measurement methods, and, as such, are not intended to be summaries of all performance measures being used by the subject organizations.

V.A. General Performance Measurement

Bechtel Corporation is a global construction company that specializes in the construction, overhaul and repair of large and complex industrial facilities, including nuclear and conventional power plants. Bechtel is anticipating some growth in demand for new nuclear power plants and is examining its organizational structure and its design, planning, and production methods to better positions itself in what it sees will be a very competitive future construction market.

Like many U.S. shipyards, Bechtel has traditionally used a systems-oriented approach to design and construction, with design engineering largely segregated from production engineering and production. Capt. Art Clark (ret.), former commanding officer of Philadelphia Naval Shipyard and now a senior management official with Bechtel, identified that the company could benefit from the implementation of product-oriented design and construction (PODAC) methods that have been researched by the NSRP and applied, to greater or lesser degrees, by some U.S. shipyards. Representatives of Bechtel have been traveling to U.S. shipyards, and have also visited the NSRP Documentation Center, to learn more about PODAC methods and supporting organizational structures.

Because of Bechtel's traditional system-oriented approach to design, construction and accounting, it has traditionally attempted to measure project cost and schedule performance based on a system-oriented product structure. Bechtel management representatives expressed that this approach to performance measurement has been fairly useless from the standpoint of controlling and improving operations. Performance measurement at Bechtel seems to be at about the same level of evolution as performance measurement at U.S. shipyards, which continue to use system-oriented design, construction, and accounting methods. Bechtel's management representatives were very interested in this research project, and asked for a copy of the final report. These representatives also stated that they view U.S. shipyards as potentially formidable future competitors in industrial construction, particularly as reductions in new Navy construction force shipyards to search for new markets.

V.B. Productivity Measurement

Competitive companies, including shipyards, measure the productivity of each process creating an interim product to help control day-to-day operations and to monitor process improvement efforts. One approach to measuring and improving productivity is to equate inputs and outputs to dollars, and to put them in the form of a balance sheet or income statement, with the intent to produce and maximize a "profit" for the work center. Here is a discussion of how Chrysler Corporation's Trenton Engine Plant has recently implemented this type of productivity measurement.

There is some incentive to increase output at Chrysler's U.S. engine plants economically in order to reduce the importation of engines from Mitsubishi. The Trenton Engine Plant produces about 2000 engines per day, and in 1991 the crankshaft manufacturing area was the bottleneck for production. The crankshaft manufacturing process consists of approximately 30 machining stations, with castings or forgings as the raw material input to the line, and completed crankshafts as the output.

The production manager of this area, Mr. Jamie Benini, decided to implement a daily "income statement" for the crankshaft manufacturing line based on similar performance measurement methods implemented at Texas Eastman Company in 1988 for some of its chemical production facilities.[5] This income statement identified the sales, or total value of crankshafts produced each day, all of the costs associated with the production of these crankshafts, including all direct and indirect costs, maintenance costs, energy costs, and quality-related costs, and finally a daily profit or loss equal to sales minus costs. The sales value of a crankshaft was estimated based on open market prices for similar components and on estimates of the cost of the raw casting/forging plus the value added during the machining processes. The sales value was earned 50% at the specific machining station identified to be the bottleneck in the line and 50% at the end of the line. This provided some incentive to improve the efficiency of the bottleneck in the line. Quality-related internal failure costs were estimated each day to be the value of a completed crankshaft per each crankshaft identified as unsatisfactory that day at final inspection. Quality-related external failure cost was estimated to be the value of a completed engine for every engine failure caused by a crankshaft problem per day, because the external failure of a crankshaft usually appeared during engine testing and resulted in the scrapping of an engine. The resulting sales, cost, and profit/loss data replaced the traditional cost and schedule variances as the performance measurements for this area.

Production workers collected all cost data during all three shifts and quickly gained an understanding of the trade-offs between costs and sales. Emphasis quickly shifted from getting finished product out the door to improving throughput at bottleneck operations, improving and assuring quality using Taguchi methods and SQC at machining stations, and increasing preventive maintenance of machines and tooling. These efforts resulted in significant increases in the crankshaft manufacturing area's "profitability" and productivity. Because of this success, another ten production areas in the same plant (about one third of the facility) have adopted the same type of income statements to measure performance. Chrysler is now in the process of redefining its performance measurement methods for all of its manufacturing facilities, and Mr. Benini is part of this task team.

Mr. Benini emphasized that the work involved with changing performance measurement methods is about 20% technical and 80% cultural. Any effort like this requires a shared vision (their's was "Get Mitsubishi! "), and a champion in top management with the energy to see the effort through and get results. He emphasized that a performance measurement system should focus on the few most important things, be as simple as possible, be driven more by a need to nurture positive behavior than by a need to value inputs and outputs accurately (they used estimates for sales value and many costs), provide feedback in real time if possible, encourage teamwork and problem solving at all levels, and provide recognition for success. Education and training of managers and production workers in problem-solving techniques, such as SQC and Taguchi methods, is essential. It is also vitally important to include the costs of quality, as many people in production and management are simply unaware of the magnitude of these costs.

V.C. Cost Of Quality Measurement

The measurement of quality has been a subject of increasing interest to all U.S. businesses, including shipyards, over the past 20 years. Many companies are just beginning to understand the relationships between customer satisfaction, business operations, and cost. As U.S. shipyards begin the transition to more commercial work, they will need to have a clear understanding of how customer satisfaction and quality will affect their operations and costs. One way that many companies have begun to understand these relationships is through the calculation of quality costs. Next is a brief discussion of Texas Instruments' implementation of quality cost measurement.

In 1980, Texas Instruments abandoned the quality cost trade-off (Juran) model and shifted to the total quality (Deming) model, see Figure 8 and 9. The trade-off model shows diminishing returns to increasing investment in quality conformance (prevention and appraisal), and also shows quality failure costs (internal and external) to be very high only for relatively high failure rates. This model, therefore, contends that there is a minimum level of overall quality costs, which allow some internal and external failures, and that the relationship between conformance and failure costs is static over time for a given process.

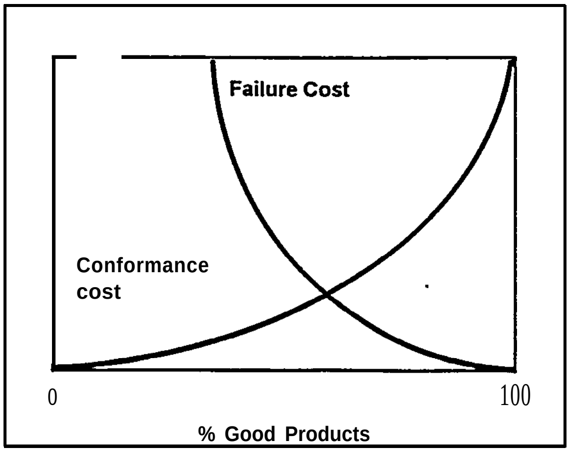


Figure 8
Trade-Off Model

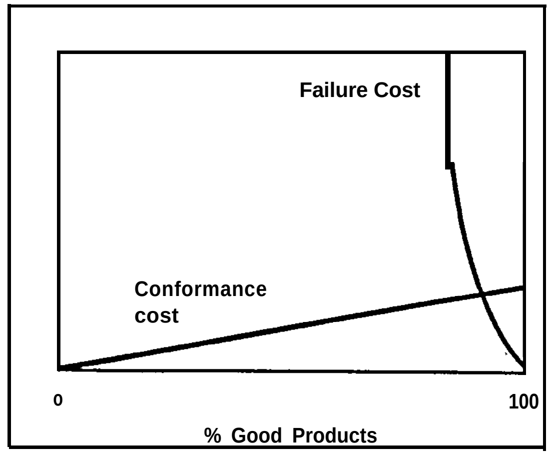


Figure 9
Total Quality Model

On the other hand, the total quality model contends that the cost of failure, especially external failure, is significantly greater than what can be easily identified and quantified. It is very difficult to place value on lost reputation and goodwill due to even a few external failures. Many quality experts, including Deming, state that the actual cost of failures is several orders of magnitude higher than what is commonly recognized and easily identified directly. The Chrysler production manager identified in the previous section, stated that a material flaw identified in a crankshaft casting prior to machining would cost the company less than $5.00; if the flaw were recognized after machining, the associated cost would be about $20.00; if such a flaw resulted in an engine failure in the plant, the resulting cost would be over $500; and if such a flaw resulted in an engine failure after the sale of the vehicle, the associated identifiable cost of repair would be several thousand dollars, and the resulting cost associated with the loss of goodwill and reputation would be enormous.

The total quality model also recognizes that over time the conformance cost required to maintain a given level of quality declines, or, to state this differently, for a constant level of conformance cost, quality will improve over time. Therefore, the total quality model drives an organization toward zero defects, where overall quality cost will be at a minimum.

When Texas Instruments first determined that they should strive for zero defects, company managers knew that they needed a tool that would allow them to look at long term quality cost and quality improvement trends[6] (Harvard Business School Case Study #9-1 89-029). For this reason they initiated cost of quality measurement. See the previous section on quality measurement for a detailed description of cost of quality measurement and lists of types of conformance costs (prevention and appraisal) and failure costs (internal and external). Between the initiation of the system in 1982 and the end of 1987 the cost of quality for Texas Instruments Materials and Controls Group dropped form 10.7% of sales to 7.8% of sales. Reductions occurred in all four areas of quality cost: prevention, appraisal, internal failure, and external failure. Most importantly, failure costs dropped from 6.2 % of sales to 3.7 % of sales.

Cost of quality measurement can provide significant benefits, such as making it easier to identify overall quality-related cost trends, to see trade-offs between prevention and correction, and to relate manufacturing information to business-oriented managers. However, cost of quality measurement provides aggregated information at such a high level that it is not a useful tool for identifying and diagnosing specific quality-related problems. Yields, defect rates, and data from SQC efforts are much more useful quality measures for day-to-day control of operations. Cost of quality measurement also does not capture indirect costs of quality, such as the cost of schedule delay resulting from the internal failure of a component. It is also subject to the accuracy of the accounting system and to the errors or bias of managers who report regularly the percentage of their resources they consider to be conformance-related or failure-related costs. Quality-related terms such as “rework” must be clearly and consistently defined throughout an organization to assure that all direct quality-related costs are captured; in many manufacturing organizations, doing a job more than once before it is right is incorrectly considered to be “normal practice, ” rather than rework. Finally, as new quality costs become quantifiable and are added to the cost of quality system, it is important to communicate that the resulting increases in quality cost are due to these additions, and not due to other factors. It is important to identify and include as many quality-related costs as possible when the system is initiated to prevent misunderstandings later due to the addition of newly quantified quality-related costs.

V.D. Cost Of Ownership Measurement

The measurement of costs and cost trends over time is vitally important for day-to-day control of operations, for determining the long-term effects of operational changes, and for providing a rational basis for future cost projections. One component of total cost is the cost of materials and components bought by a company from suppliers and vendors. Texas Instruments, Northrop, Black & Decker, McDonnell Douglas, DEC, Rockwell International, and many other companies are measuring the *cost of ownership* for materials and components supplied to them by other companies.’ The cost of ownership includes not only the purchase price of specific material, but also the cost associated with purchasing this material, the cost of holding this material in inventory, the cost of vendor-related quality for this material, and the cost of off-schedule delivery. If two suppliers offer an equivalent component at the same purchase price, but the paperwork required for the purchase of this component is greater for one supplier than for the other, then the purchasing cost will also be greater for the component from the supplier requiring the additional paperwork. Similarly, if two suppliers offer equivalent components at the same price, but one supplier provides packaging that better protects their components from the environment during shipping and storage, then the cost of holding the protected components in inventory will be less, and the vendor-related quality cost will likely be less due to decreased damage of components during shipping. The costs associated with off-schedule delivery are generally the cost of storage related to early delivery and the cost of project delays due to late delivery. A vendor's delivery performance to schedule will have a direct effect on the overall cost of shipyard operations, particularly for material and components required for critical-path work.

All of the companies listed above have recognized that material supplied by vendors costs more than the purchase price, and that the overall cost of owning this material should be used as the basis for selecting suppliers and vendors. Some U.S. shipyards, including Newport News Shipbuilding, have also begun to measure the cost of ownership for their purchased materials and components. There are various ways to establish the cost of ownership for vendor-supplied material and components, ranging from establishing absolute costs for the above-mentioned factors from available and accurate cost history, to establishing a simple factor by which to multiply the purchase price, based on limited quantitative data and past qualitative experience. The availability of concrete cost data on ordering costs, storage costs, quality costs, and delivery schedule costs will largely determine the approach taken in establishing cost of ownership.

Newport News Shipbuilding's program is called SMART, or the *Supplier Material Analysis Rating Technique.* This program determines "nonproductive effort" costs for each supplier-specific transaction, adds these costs to the purchase cost, and then divides this sum by the purchase cost to establish a *SMART Factor* for the vendor. This *SMART Factor is* then multiplied by the bid price provided by the vendor the next time a request-for-quote is issued for the same item; this establishes the potential cost of ownership for that item from that vendor. "Nonproductive effort" is defined to include work associated with the resolution of receipt inspection discrepancies, the review and disposition of requests for vendor information, and the affects of late deliveries. This program is very similar to that used at Northrop Aircraft Division (NAD), called the *Supplier Performance Rating System* (SPRS).

V.E. Rate Of Learning Measurement

A shipyard that has established an environment of continuous improvement has institutionalized processes of learning. In order to be competitive in the commercial market, a shipyard must not only have established an environment of continuous improvement, b ut it must also be able to learn as fast as, or faster than, its competitors. Because the ability to learn at specific rates is important, i t is also important to be able to measure a company's rate of learning. Following is a brief discussion of Analog Devices' implementation of a methodology for measuring rates of learning within their company.

Analog Devices (ADI) produces integrated circuits and electronic devices and systems primarily for converting analog information into digital data. ADI's products are used in computers, aircraft sensors, scientific and medical instruments, and consumer electronics. In the mid- 1980s, ADI began to see business stagnate in spite of their high quality work force and engineers, continual investment in the latest technology for design and production, and long-term business focus. ADI concluded that they simply were not learning as a company as fast as their competitors. In fact, their chairman and president, Mr. Ray Stata, went as far as to argue that the rate at which individuals and organizations learn may be their only sustainable competitive advantage. This learning should manifest itself in competitive rates of process improvements. The problem then was to determine what rates of process improvement were necessary to remain competitive, and to establish realistic process improvement targets over time, based on present performance and on projections of the performance of competitors.

ADI studied the work of Dr. Jay Forrester of MIT, and hired an MIT graduate, Mr. Art Schneiderman, who had done some research in learning models for " manufacturing and business. Mr. Schneiderman had identified that, in organizations with very successful continuous improvement processes, learning and process improvement occurred at a rate such that when some significant measure of process performance requiring improvement, such as defect rate or process duration, was plotted on semilog paper versus time, it would form a straight line that decreased over time, as shown in Figure 10. This line would continue downward at a constant rate until some inherent limitations of the process would prevent more improvement, at which time a process breakthrough would be required for improvement to continue.

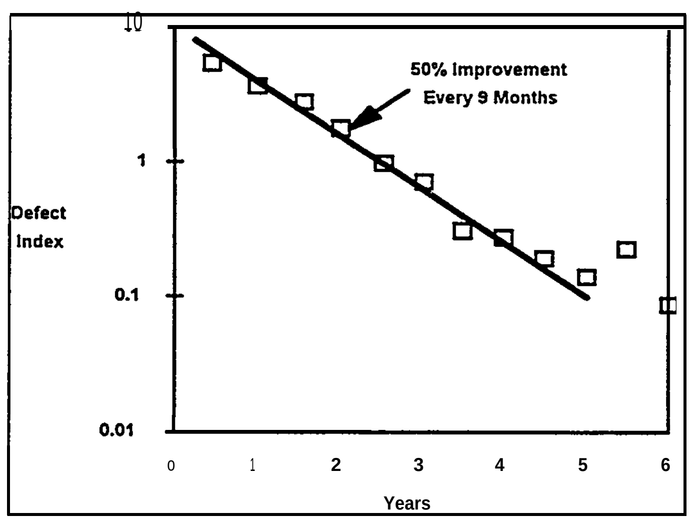


Figure 10
Example "Half-Life" Graph for a Particular Process

Mr. Schneiderman studied many different types of processes by identifying and measuring a significant *defect index* for each process, such as error rate, cycle time, inventory level, absenteeism, accident rate, late delivery rate, percent part defects, set-up time, and order lead time. He found that this learning model applied to most types of processes. ADI and Mr. Schneiderman established the length of time it would take to make a *50* percent reduction in the defect index of each process, and called this the process *half-life* measurement. They found that processes with high technical and organizational complexity had process half-lives significantly longer than processes with lower technical or organizational complexity, with organizational complexity being the most important factor. ADI published quarterly reports showing the half-life graphs and identifying the half-lives for each process. Here is a short list of some 1989 ADI half-life measurements. These numbers represent rates of learning and improvement expressed in half-life months, or the number of months required to reduce the process defect indices identified by half. This information applies only to ADI for the year 1989.

Process Defect Index	Half-Life (months)
Errors in purchase orders	2.3
Failure rate, dip soldering process	3.7
Vendor defect level, capacitors	5.7
Accounting miscodes	6.4
Defects per unit, line assembly	7.6
Scrap costs, total manufacturing	13.8
Manufacturing cycle time	16.9
Accident rate	21.5
Late deliveries to customer (+0,-2 weeks)	30.4
Product development cycle time	55.3

By identifying its present process performance levels and improvement rates, and those of competitors, a company can determine whether it is learning fast enough to compete and establish process performance improvement targets for the future. The approach generally used to learn and to achieve these process improvements is the classic plan-do-check-act (PDCA) problem solving approach. To preseme learning that is achieved through the PDCA process, competitive companies incorporate all improvements into normal operations through the creation and regular revision of process procedures and targets.

VI. Alternative Shipyard Performance Measurement Methods/Examples

The data presented in the production and support performance measurement methods/examples sections have been sanitized. Actual cost and productivity data are considered PBI company confidential.

VI.A. Production Areas

VI.A.1. Background

Blasting (surface preparation) and Painting (surface coating) operations were selected by SP-8 as the production areas for focused testing of various performance measures. Historically the surface preparation and coating functions have been difficult for many shipyards to manage. Data show that the surface preparation and coating functions are highly labor-intensive processes and account for a large portion of the total ship construction labor costs. Shipbuilding activities performed at Peterson Builders, Inc. (PBI) during the project show that estimated surface preparation and coating labor costs range from 6.3 % to 13.5% of the total ship construction labor cost. Data on surface preparation and coating estimating and scheduling are insufficient, rework costs caused by excess hot work are unpredictable and usually high, and quality requirements are often unclear.

Even though the project team understood the consequences of using direct labor costs to estimate the overall process costs, it was determined that the analysis of direct labor costs for this case study would be appropriate, see Section III.B. 1. As the performance measures for the production area continue to grow and become more reliable, it is anticipated that other cost factors will be incorporated.

PBI was contracted for the construction and delivery of a 96 foot passenger/car ferry, *Miller Ferry,* for the Miller Boat Line, Inc. of Put-in-Bay, Ohio. With the start of construction in August 1992 and delivery April 1993, the *Miller Feny* posed as the ideal candidate for testing alternative production performance measures. The relatively small size of the *Miller Ferry also* allowed for the analysis of detailed surface preparation and coating information without overwhelming the project team.

It was very important to identify and develop the performance measurement needs of the Paint Department production shop. The production shop's goals on the *Miller Ferry* included producing a quality product within established budgets and schedules. The production shop also expected to identify long term process improvements and to develop accurate bidding and estimating data.

It was determined that to manage the surface preparation and coating operations effectively, the production shop needs to develop cost and schedule measures, productivity/efficiency measures, and quality measures. The production shop also requested that the measurement information be generated weekly to assist in monitoring this short-duration construction project.

The data presented in the production performance measurement methods/examples section have been sanitized. Actual cost and productivity data are considered PBI company confidential.

VI.A.2 Cost, Schedule, and Productivity Measurements

Early in the investigation of the surface preparation and coating activities on the *Miller Ferry*, it was necessary to define the manner in which the work was broken down. Surface preparation and coating work elements can be best defined by an area or compartment. In other words, the interim products produced by the surface preparation and coating operations can best be identified by the surface area of each space or compartment. The original work breakdown for the *Miller Ferry* was obtained, and, with the assistance of the production shop, was revised in order to reflect the products actually produced, as shown in Figure 11.

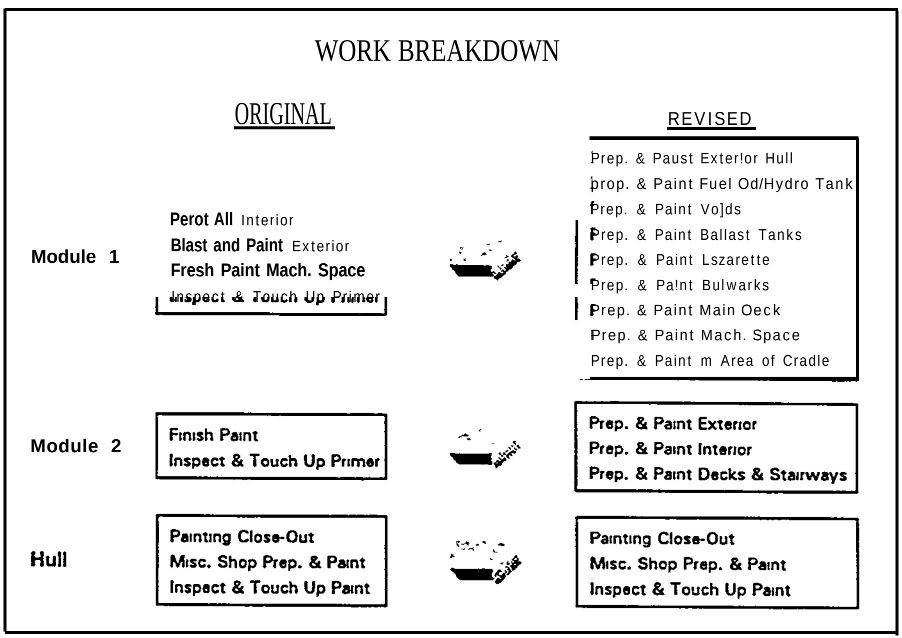


Figure 11
Miller Feny Work Breakdown Development

Work packages were established for each work element. Utilizing the experience of the production shop personnel, overall work package labor budgets were derived for both surface-preparation and coating operations.

After further analyzing the processes and outputs produced by the production shop, similarities were identified among work packages. Work packages with similar process and output characteristics were grouped together for the measurement of productivity. For example, the voids, ballast tanks, and lazarette were grouped together because of their similar process and output characteristics. Process and output characteristics analyzed for grouping purposes included percent stiffened surfaces, percent insulated surfaces, accessibility, congestion. work position, surface profile requirements prior to paint, number of paint coats, type of paint, and thickness of paint.

Meaningful cost and schedule, and productivity measurements also required the development of accurate schedules. Schedule accuracy directly affects the cost and schedule variances to be measured. Labor schedules were developed to include both time periods (weekly) and estimated allocation of surface preparation and coating labor hours, as shown as the Budgeted Cost of Work Scheduled (BCWS) or Scheduled Progress in Tables 2 and 3. This information was entered into a spreadsheet.

Table 2
BCWS (Scheduled Progress)
Work Elements: <u>Surface preparation -</u> Voids, Ballast Tanks, and Lazarrette

Week	Work Package (Labor Hours)			Total
	Voids	Ballast Tanks	Lazarette	
1		75		75
2	50	25		75
3	100		50	150
4	75		100	175
6			25	25
7				0
8				0
9				0
10				0
Target Labor Hours	300	100	200	600

Table 3
BCWS (Scheduled Progress)
Work Elements: Surface Coating - Voids, Ballast Tanks, and Lazarrette

Week	Work Package (Labor Hours)			Total
	Voids	Ballast Tanks	Lazarette	
1				0
2				0
3		30		30
4		30		30
5		40		40
6	40			40
7	60			60
8			25	25
9			50	50
10			25	25
Target Labor Hours	100	100	100	300

In addition, meaningful productivity measurements needed to be defined to reflect the outputs of the surface preparation and coating operations. For the Miller Ferry, square footage of surface area completed, either through surface preparation or coating, was defined as the output. The resulting productivity measurement, output per input, for this project then was square feet completed per labor hour expended.

Utilizing an in-house CAD system, surface area for each work package was determined, as shown in Appendix C. The total square feet per work package was based on the designed number of times the process was performed. In other words, if a work package requires two coats of paint, the total square footage would be twice the area of the space.

As with labor costs, the amount of surface area to be completed must reflect the schedule in order to identify output variances. Square footage output was defined to suit the production schedules and was entered into a spreadsheet, as shown in Tables 4 and 5.

Table 4
Planned Square Footage
Work Elements Surface Preparation - Voids, Ballast Tanks, and Lazarrette

Week	Work Package (square Feet)			Total
	Voids	**Ballast Tanks**	Lazarette	
1		6000		6000
2	1500	2000		3500
3	3500		1250	4750
4	3000		2500	5500
5	2000		1150	3150
6			1100	1100
7				0
Total	10000	8000	6000	24000"

Table 5
Planned Square Footage
Work Elements: **Surface Coating** - Voids, Ballast Tanks, and Lazarrette

Week	**Work Package (Square Feet)**			**Total**
	Voids	**Ballast Tanks**	**Lazarette**	
1				0
2				0
3		4500		4500
4		5000		5000
5		6500		6500
6	12000			12000
7	8000			8000
8			3500	3500
9			5000	5000
10			3500	3500
Total	20000	16000	12000	48000

The remaining key elements needed to establish meaningful performance measures were accurate charging and progressing methods. Labor charging is completed each day by the worker. Labor charges are made at the work package level, but the production shop also utilized operation type codes to identify the type of work performed, as seen in Appendix D. These detailed operation type codes allowed the project team to identify the work elements being performed easily and could also be used as a tool for later analysis of performance variances.

Presently, no formal mechanisms exist for the production shop to accurately determine and report progress for surface preparation and coating operations. To generate cost, schedule, and productivity information, subjective progress input was received from experienced personnel in the production shop and entered into a spreadsheet, as shown in Tables 6 and 7.

Table 6
Percent Progress
Work Elements: Surface Preparation - Voids, Ballast Tanks, and Lazarrette

Week	Work Package (Percent)		
	Voids	Ballast Tanks	Lazarette
1	10%	15%	
2	20%	25%	
3	50%	50%	
4	20 %	10%	
5			50%
6			40%
7			10%
8			
9			
10			
Total	100%	100%	100%

Table 7
Percent Progress
Work Elements: Surface Coating - Voids, Ballast Tanks, and Lazarrette

Week	Work Package (Percent)		
	Voids	Ballast Tanks	Lazarette
1			
2			
3			
4	5%		
5	25%	30%	
6	60%	30%	
7		20%	
8	10%	20 %	20%
9			20%
10			60%
Total	100%	100%	100%

Weekly labor cost reports were generated from the company's computerized labor system. These labor reports were sorted by work package and operation type code. Labor information from these reports was entered into a spreadsheet for further analysis, as shown as the Actual Cost of Work Performed (ACWP) or Spent Hours in Tables 8 and 9.

Table 8
ACWP (Spent Hours)
Work Elements: Surface preparation - Voids, Ballast Tanks, and Lazarrette

Week	Work Package (Labor Hours)			Total
	Voids	Ballast Tanks	Lazarette	
1	35	20		55
6			30	30
7			30	30
8				0
9				0
10				0
Total	330	150	140	620

Table 9
ACWP (Spent Hours)
Work Elements: Surface Coating - Voids, Ballast Tanks, and Lazarrette

Week	Work Package (Labor Hours)			Total
	Voids	Ballast Tanks	Lazarette	
1				0
2				0
3				0
4	10			10
5	10	50		60
6	40	70		110
7		20		20
8	30		5	35
9			5	5
10			40	40
Total	90	140	50	280

Earned progress, Budgeted Cost of Work Performed (BCWP), was calculated by multiplying the percent progress and total budget (BCWS total) information already found in the spreadsheet, as shown in Tables 10 and 11. (BCWP = BCWS total multiplied by percent progress)

Table 10
BCWP (Earned Progress)
Work Elements: Surface Preparation - Voids, Ballast Tanks, and Lazarrette

Week	Work Package (Labor Hours)			Total
	Voids	Ballast Tanks	Lazarette	
1	30	15		45
2	60	25		85
3	150	50		200
				00
6			80	80
7			20	20
8				0
				o
10				0
Total	300	100	200	600

Table 11
BCWP (Earned Progress)
Work Elements: Surface Coating - Voids, Ballast Tanks, and Lazarrette

Week	Work Package (Labor Hours)			Total
	Voids	Ballast Tanks	Lazarette	
1				0
2				0
3				0
4	5			5
5	25	30		55
6	60	30		90
7		20		20
8	10	20	20	50
9			20	20
10			60	60
Total	100	100	100	300

As with the percent progress information, the production shop personnel also reported estimates on the amount of actual output produced, in square feet, for each work package. This information was entered into another spreadsheet, as shown in Tables 12 and 13.

Table 12
Actual Square Footage
Work Elements: Surface preparation - Voids, Ballast Tanks, and Lazarrette

Week	Work Package (Square Feet)			Total
	Voids	Ballast Tanks	Lazarette	
1	1000	1200		2200
2	2000	2000		4000
3	5000	800		5800
4	2000	4000		6000
5			3000	3000
6			2400	2400
7			600	600
8				0
9				0
10				0
Total	10000	8000	6000	240013

Table 13
Actual Square Footage
Work Elements: Surface Coating - Voids, Ballast Tanks, and Lazarrette

Week	Work Package (Square Feet)			Total
	Voids	Ballast Tanks	Lazarette	
1				0
2				o
3				0
4	1000			1000
5	5000	4800		9800
6	12000	4800		16800
7		3200		3200
8	2000	3200	2400	7600
9			2400	2400°
10			7200	7200
Total	20000	16000	12000	48000

Using the information already existing in the spreadsheet, cost and schedule variance calculations were performed, as shown in Tables 14 to 17. These calculations are based on the following formulas:

Absolute Cost Variance = ACWP - BCWP (labor hours)
Percent Cost Variance = (ACWP - BCWP)/BCWP
Absolute Schedule Variance = BCWP - BCWS (labor hours)
Percent Schedule Variance = (BCWP - BCWS)/BCWS

It should be noted that the sign convention for the cost variance formulas is presented differently than earlier in the report, in order show variances in an intuitive manner (positive for excessive costs and negative for less than planned costs).

Table 14
Cost Variances
Work Elements: Surface Preparation - Voids, Ballast Tanks, and Lazarrette

Week	Weekly Cost Variance (Labor Hours)	Cumulative Cost Variance (Labor Hours)	Weekly Cost Variance (%)	Cumulative Cost Variance (%)
1	10	10	22 2	22 %
2	0	10	0%	8%
3	-25	-15	-13 %	-5 %
4	70	55	100%	14%
5	5	60	5%	12%
6	-50	10	-63 %	2%
7	10	20	50%	3%
8	0	20	0%	3%
9	0	20	0%	3%
10	0	20	0%	3%

(+) Cost Variance = Over Budget, (-) Cost Variance = Under Budget

Table 15
Schedule Variances
Work Elements: Surface Preparation - Voids, Ballast Tanks, and Lazarrette

Week	Weddy Schd. Variance (Labor Hours)	Cumulative Schd. Variance (Labor Hours)	Weddy Schd. Variance (%)	Cumulative Schd. Variance (%)
1	-30	-30	-40 %	-40 %
2	10	-20	13%	-13%
3	50	30	33%	10%
4	-105	-75	-60%	-16%
5	0	-75	0%	-13%
6	55	-20	220 %	-3 %
7	20	0	0%	0%
8	0	0	0%	0%
9	0	0	0%	0%
10	0	0	0%	0%

(+) Schedule Variance = Ahead of Schedule, (-) Schedule Variance = Behind Schedule

Table 16
Cost Variances
Work Elements: Surface Coating - Voids, Ballast Tanks, and Lazarrette

Week	Weekly Cost Variance (Labor Hours)	Cumulative Cost Variance (Labor Hours)	Weekly Cost Variance (%)	Cumulative Cost Variance (%)
1	0	0	0%	0%
2	0	0	o%	0%
3	0	0	0%	0%
4	5	5	100%	100%
5	5	10	9%	17%
6	20	30	22 %	33%
7	0	30	0%	20%
8	-15	15	-30%	7%
9	-15	0	-75 %	0%
10	-20	-20	-33 %	-7 %

(+) Cost Variance = Over Budget, (-) Cost Variance = Under Budget

Table 17
Schedule Variances
Work Elements: Surface Coating - Voids, Ballast Tanks, and Lazarrette

Week	Weekly Schd. Variance (Labor Hours)	Cumulative Schd. Variance (Labor Hours)	Weekly Schd. Variance (%)	Cumulative Schd. Variance (%)
1	0	0	0%	0%
2	0	0	0%	0%
3	-30	-30	-l00%	-100%
4	-25	-55	-83 %	-92 %
5	15	-40	38%	-40 %
6	50	10	125 %	7%
7	-40	-30	-67 %	-15%
8	25	-5	100%	-2 %
9	-30	-35	-60%	-13%
10	35	0	140%	0%

(+) Schedule Variance = Ahead of Schedule, (-) Schedule Variance = Behind Schedule

Graphic representations of the cost and schedule performance measures were provided to the production shop on a weekly basis, including the traditional CSCS data representation, as shown in Figures 12 to 21.

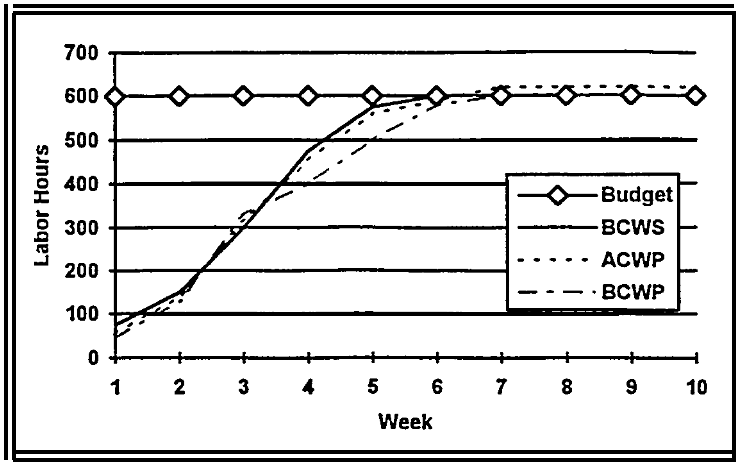


Figure 12
Surface Preparation - CSCS Data Representation

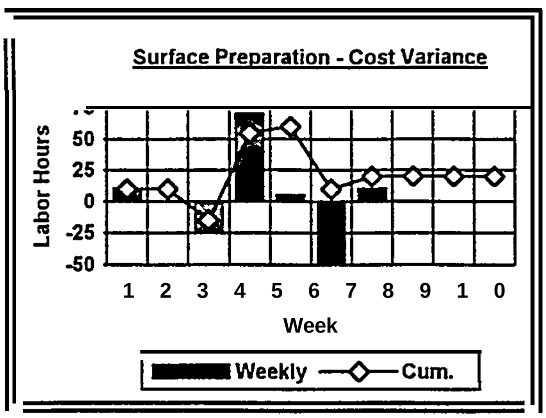


Figure 13
Cost Variance - Labor Hours

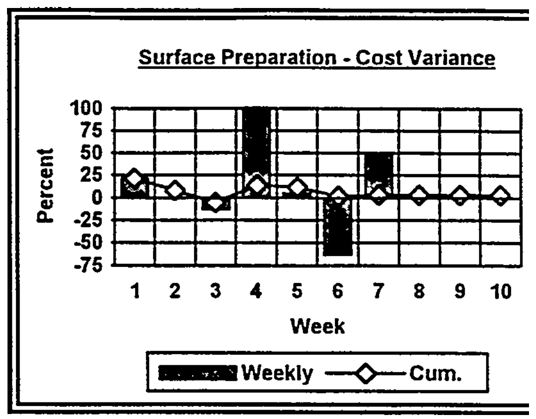


Figure 14
Cost Variance - Percent

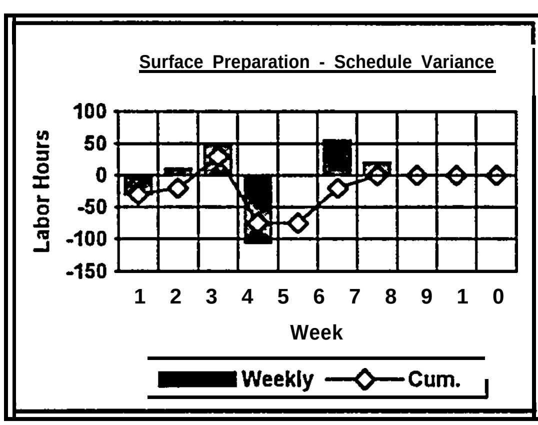


Figure 15
Schedule Variance - Labor Hours

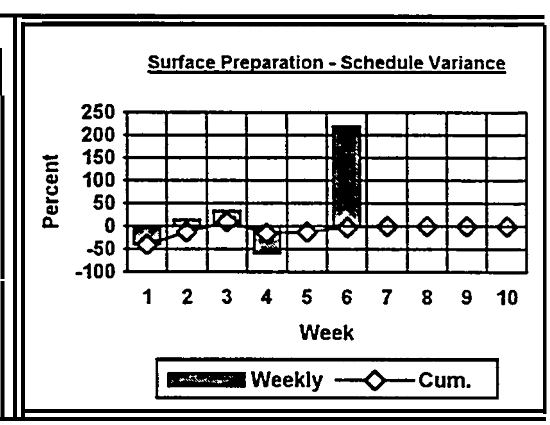


Figure 16
Schedule Variance - Percent

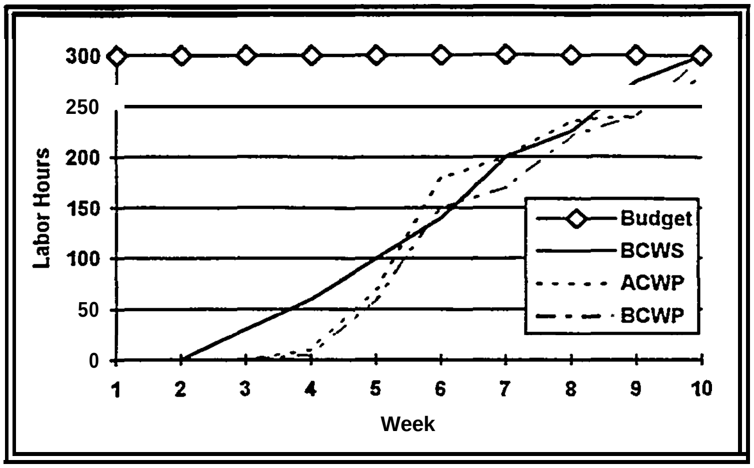


Figure 17
Surface Coating - CSCS Data Representation

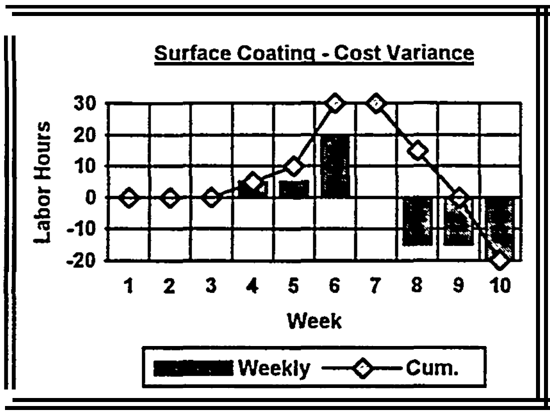


Figure 18
Cost Variance - Labor Hours

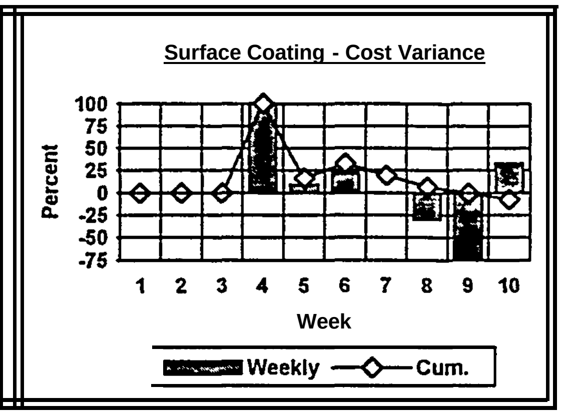


Figure 19
Cost Variance - Percent

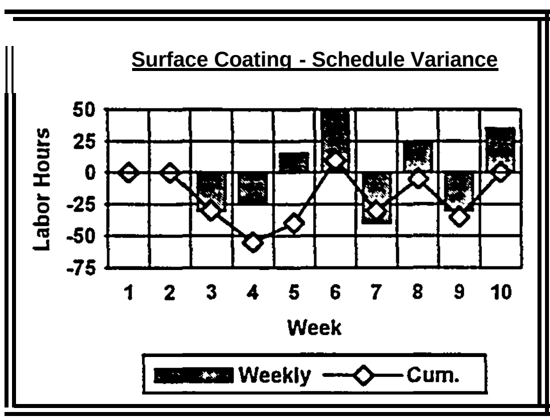


Figure 20
Schedule Variance - Labor Hours

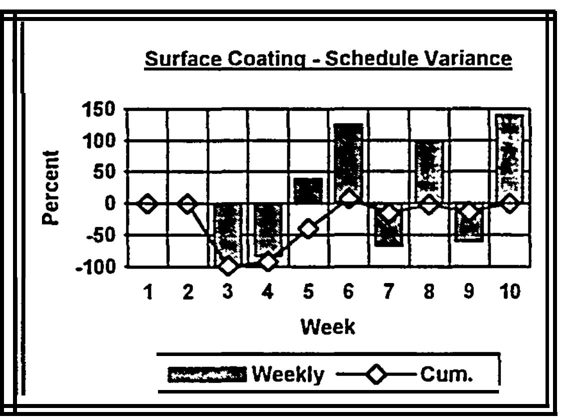


Figure 21
Schedule Variance - Percent

Productivity levels and output variances were generated weekly, as shown in Tables 18 and 19 and in Figures 22 to 29.

Table 18
Productivity and Output Variances
Work Elements: Surface Preparation - Voids, Ballast Tanks, and Lazarrette

	Planned Sq.Ft.		Actual Sq.Ft.		Variance Sq.Ft.		ACWP Labor Hours		Productivity Sq.Ft./Hour	
Week	Wkly	Cum.	Wkly	Cum.	Wkly	Cum.	Wkly	Cum.	Wkly	Cum.
1	6000	6000	2200	2200	-3800	-3800	55	55	40	40
2	3500	9500	4000	6200	500	-3300	85	140	47	44
3	4750	14250	5800	12000	1050	-2250	175	315	33	38
4	5500	19750	6000	18000	500	-1750	140	455	43	40
5	3150	22900	3000	21000	-150	-1900	105	560	29	38
6	1100	24000	2400	23400	1300	-600	30	590	80	40
7		24000	600	24000	600	0	30	620	20	39
8		24000		24000		0	0	620		39
9		24000		24000		0	0	620		39
10		24000		24000		0	0	620		39

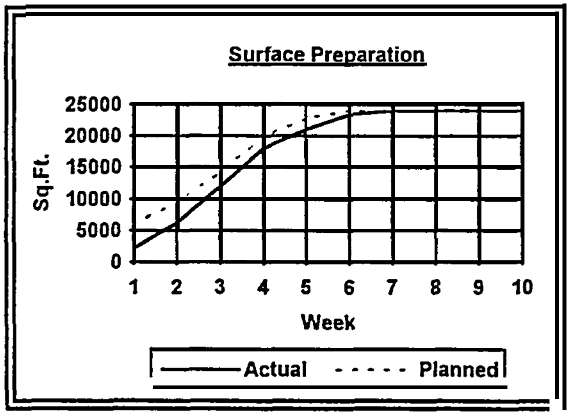


Figure 22
Actual Vs. Planned Output

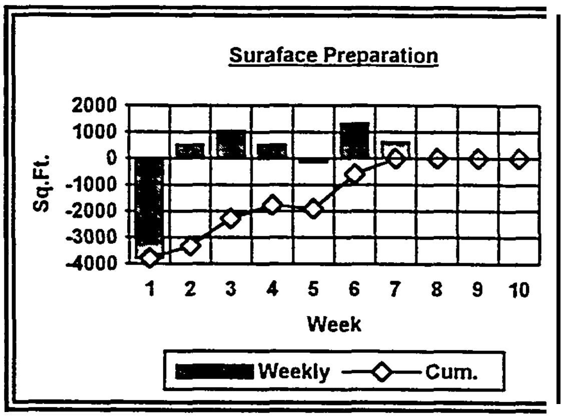


Figure 23
Weekly & Cum. Output Variances

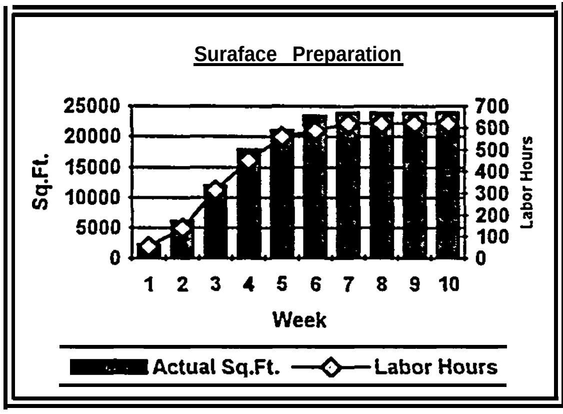


Figure 24
Weekly Output & Labor Hours

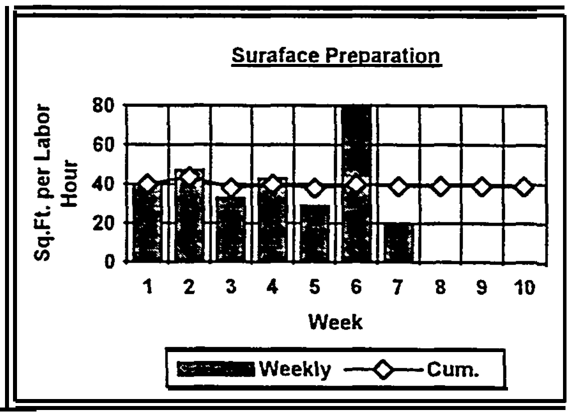


Figure 25
Weekly & Cum. Productivity

Table 19
Productivity and Output Variances
Work Elements: <u>Surface Coating</u> - Voids, Ballast Tanks, and Lazarrette

	Planned Sq.Ft.		Actual Sq.Ft.		Variance Sq.Ft.		ACWP Labor Hours		Productivity Sq.Ft./Hour	
Week	**Wkly**	**Cum.**	**Wkly**	**Cum.**	**Wkly**	**Cum.**	**Wkly**	**Cum.**	**Wkly**	**Cum.**
1		0		0		0		0		
2		0		0		0		0		
3	4500	4500		0	-4500	-4500		0		
4	5000	9500	1000	1000	-4000	-8500	10	10	100	100
5	6500	16000	9800	10800	3300	-5200	60	70	163	154
6	12000	28000	16800	27600	4800	-400	110	180	153	180
7	8000	36000	3200	30800	-4800	-5200	20	200	160	154
8	3500	39500	7600	38400	4100	-1100	35	235	217	163
9	5000	44500	2400	40800	-2600	-3700	5	240	480	170
10	3500	48000	7200	48000	3700	0	40	280	180	171

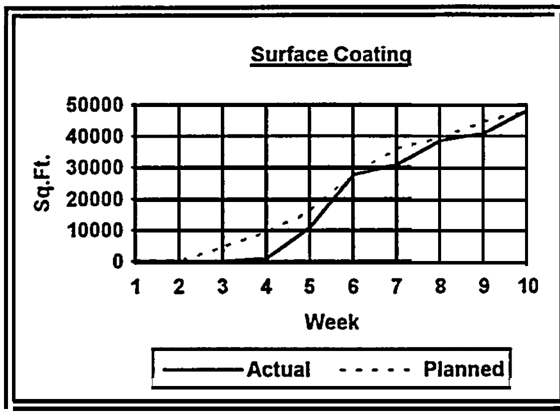


Figure 26
Actual Vs. Planned Output

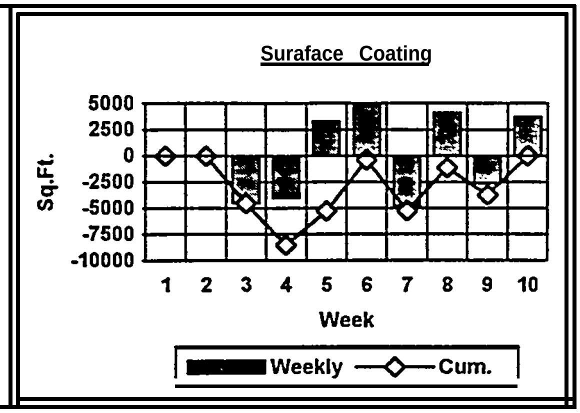


Figure 27
Weekly & Cum. Output Variances

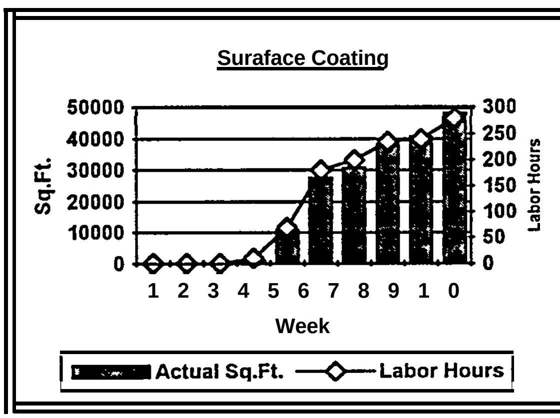


Figure 28
Weekly Output & Labor Hours

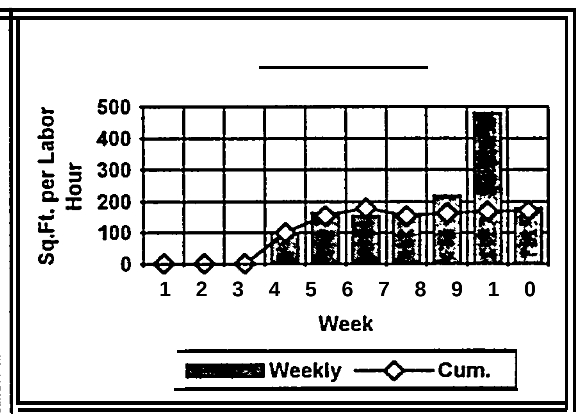


Figure 29
Weekly & Cum. Productivity

VI A.3 Quality Measurements

Information provided by the production shop and coating supplier identified the coating thickness as a critical quality characteristic. The coating system performance is directly related to the coating thickness. Target coating thicknesses were established for each coating system step. Following the completion of each step in the coating process, coating thickness readings were taken. The series of coating thickness readings were statistically analyzed and documented for use by the production shop, as shown in example output Appendix E.

Initial data showed a significant variance in coating thickness. The production shop and coating supplier were concerned that some areas completed would not contain the proper paint thickness to provide adequate protection, while other areas would have excess coating. Figure 30 shows an example normal curve with a relatively high variation in coating thickness.

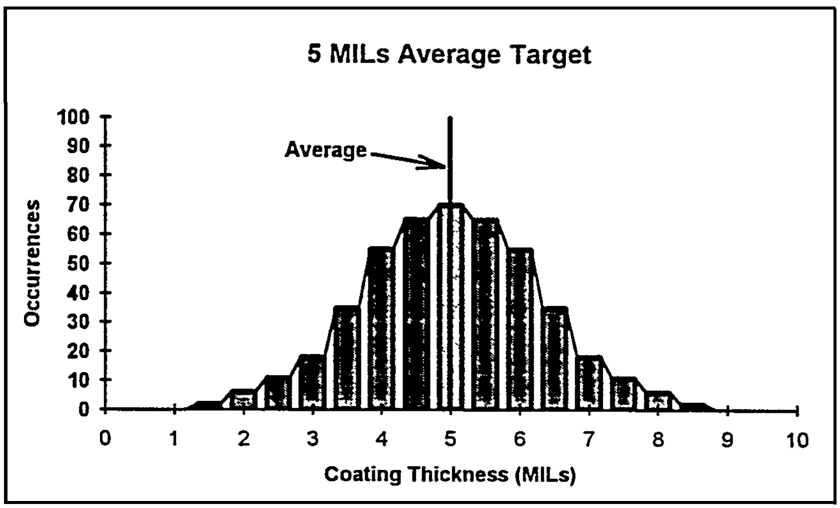


Figure 30
High Variation in Coating Thickness Readings

The coating supplier notified the production shop that for coating systems to provide adequate protection, they should be applied with no readings more than 2 MILs below the target thickness. Since the process, as depicted in Figure 30, contains data points as much as 4 MILs less that the target, the production shop must either increase the target thickness or reduce its variation.

Figure 31 shows the effects of a shift in the target thickness. Note the effect on the amount of coating being applied greater that the original target specification. In an effort to demonstrate the need for improved process control, the direct cost of applying an average coating thickness in excess of required thicknesses was calculated, as shown in Appendix F , based on existing process variation. These costs are computed using simple equations based on the amount of material necessary to cover the surface with one or more excess MILs of coating and the amount of labor required to apply the material. Therefore, a 2 MIL shift in the target thickness would increase the cost of this process by $4,462.

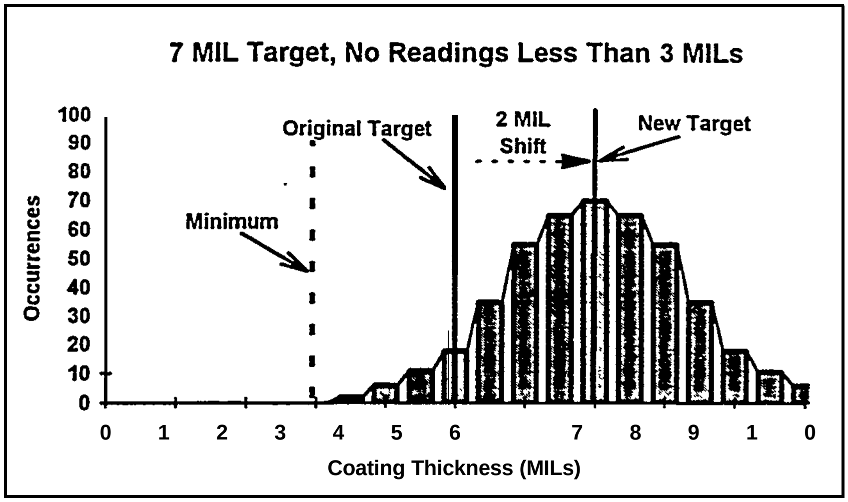


Figure 31
Shift in Process Target to Meet Minimum Requirements

Figure 32 demonstrates improved process variation in which no shift in the target coating thickness is needed to achieve the minimum requirements. Depending on the changes made to the process, no additional material and labor cost should be incurred.

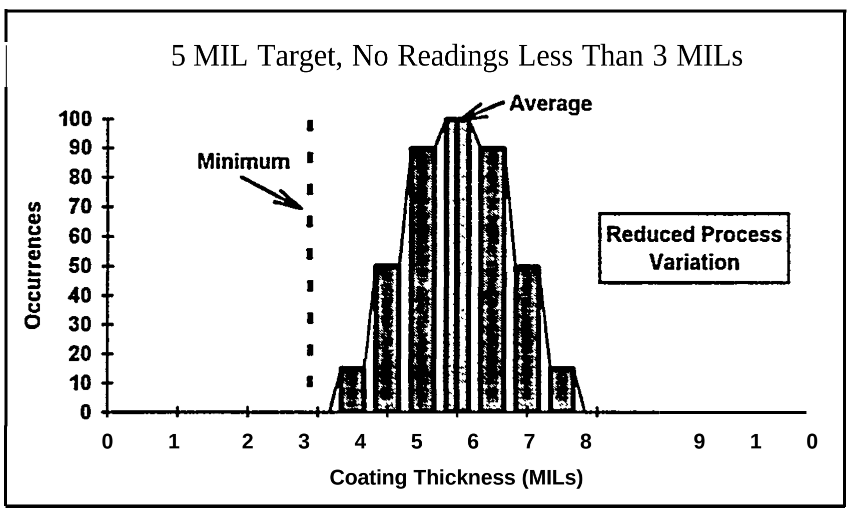


Figure 32
Reduced Process Variation to Meet Minimum Requirements

VI.A.4 Revised Performance Measurement Package

After several weeks, the production shop suggested some improvements to the presentation of the performance reports to improve communication and understanding with the shop floor personnel and upper management. See Appendix G. Two main requests of the production shop included (1) a pictorial showing the work areas in question, and (2) a forecast of end-of-project cost and schedule projections.

VI.A.5 Summary of Findings and Results

During the course of the case study work, several difficulties and benefits were encountered that had specific effects on the production shop in question.

Productivity measurements were very successful. This analysis included one of the first detailed investigations into the productivity rates achieved by the production shop. Even though these results have not been validated at this time, it appears that the production shop is well on its way to developing standard levels of performance for various product types. Accurate bidding and estimating data will result.

The paint thickness quality measurements have brought about a better understanding of the process variables encountered by the production shop personnel. This measurement is being implemented on other contracts at PBI in an effort to achieve better process control.

Poor up-front planning and coordination of trades affected the meaningfulness of the cost and schedule measurements. Even though these tools are designed to accommodate a flexible scheduling system, the project team had difficulty adjusting to frequent schedules changes. This constant modification of the production schedule introduced many of the cost and schedule variances depicted by the measurements. The project team froze the schedule late in the project because no benefits would have been obtained from continuing to adjust the schedule.

All-in-all, the goals established by the production shop for this case study were achieved. The cost and schedule measures assisted the production shop in completing the project within budget and on schedule. Productivity measurements are expected to enhance the bidding and estimating capabilities of the production shop.

VI.B. - Support Areas

VI.B.1. - Background

Input from the shipbuilding industry and the SP-8 panel indicates that improvements to performance measurement in the support function, Material Control, have a good potential to impact the shipbuilding industry positively. Material Control in the shipbuilding environment is a complicated process.

The definition of Material Control (Materials Management) used by the project team for the purpose of this case study is

> Material Control (Materials Management), a term to describe the grouping of management functions related to the complete cycle of material flow, from the purchase, receipt, inspection, and warehousing of vendor supplied material to the internal control of work-in-process.[8]

The wide scale requirements of a material-control system and the amount of information flow caused the project team to limit the scope/approach of this case study. The approach taken by the project team was to

(1) identify problem areas within material control,
(2) research measures already in use in shipbuilding and other industries,
(3) review findings with shipyard personnel to determine applicability, and
(4) utilize in-house data to generate example models.

This process was used to investigate several specific problem areas. An ideal case study for a support area would have involved the development of a total performance measurement strategy for investigating cost and schedule, productivity, and quality measures for one specific process.

During the time period of the project's case study, the material control systems at PBI were under transition. PBI was in the process of implementing new business software and procedures, which included all new material-control elements. Some complications were encountered with the software implementation that did not allow the project team to compile all the desired data within the available resources provided by the project. Much of the data obtained by the project team was compiled manually from existing reports and entered into a personal computer for analysis.

Many of the existing reports and tools already used at PBI appeared to contain elements of good performance measures. For performance measurement this information should be looked at over time, rather than just looking at a snap shot of existing conditions at any one time. In many instances when management presents data as a snap shot perspective, the data are often meaningless because there are no established targets for comparison to past performance.

The data represented in the support performance measurement methods/examples section have been sanitized. Actual data are considered PBI company confidential.

VI.B.2. - Example Material Control Measures

The problems encountered by Materials Planning/Procurement operations are significant and have a direct effect on all other shipyard material-control functions. Getting the appropriate material to the shipyard according to budget and schedule is a prerequisite to accurate, timely, and inexpensive handling and delivery of material for waterfront operations.

With the cost of materials being a significant element in the overall cost of ship construction, shipyard managers require the means to control these costs especially over the life cycle of a contract. During the project team's investigation of the Material Planning/Procurement operations, it was found that present material cost performance reporting capabilities already existed. Monthly reports were generated containing information similar to the following example, shown in Table 20.

Table 20
Material Cost Performance Report

Item	Original Budget	Available Budget	Budget Spent	Balance Available
Plate	$500	$550	$450	$100
Pipe	$200	$200	200	$0
Paint	$50	$75	$50	$25
Electrical Cable	$125	$100	$150	-$50
Insulation	$25	$25	$35	-$10
Machinery	$400	$400	$500	-$100
Totals	$1300	$1350	$1385	-$35

Expanding on this existing report, the project team suggested that it be supplemented with a graphical representation of the information over time, as shown in Figure 33.

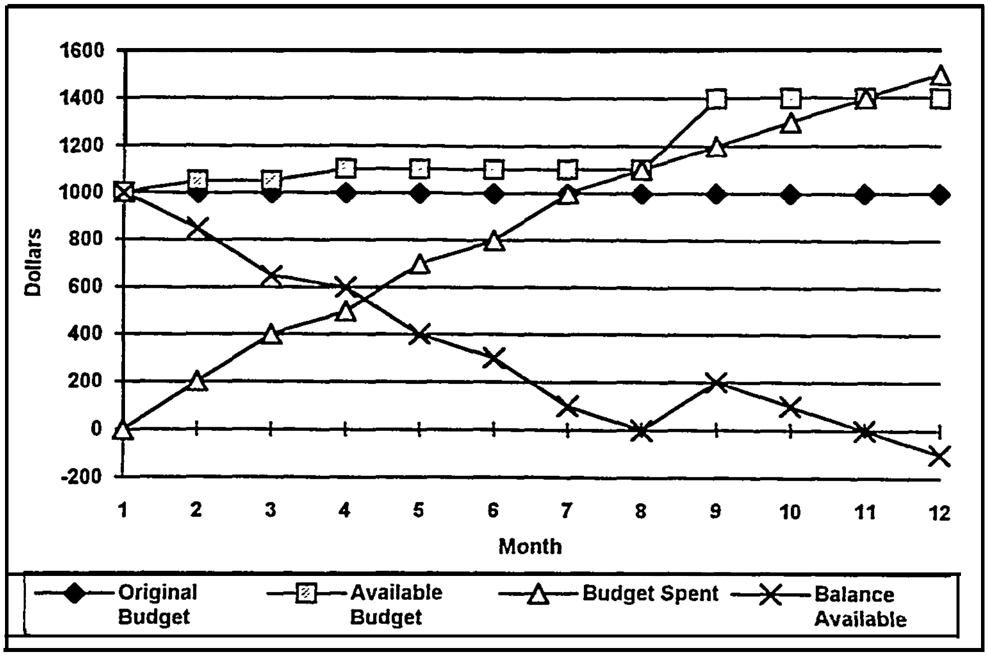


Figure 33
Procurement Cost Performance Over Time

This graphical data representation provides the shipyard manager with a general overview of the material cost performance. Targets are established, variances are easily identified, and both negative and positive trends can be managed.

Material Planning/Procurement schedule performance is based on material being available for manufacturing. Therefore, procurement's schedules are established by manufacturing's required in-yard dates. The Materials Planning/Procurement operations performance to schedule can be based on the number of items, requisitions, or purchase orders delivered to schedule or delivered late. Schedule performance can be graphically represented both as a count and as a percentage, as shown in Figures 34 and *35*.

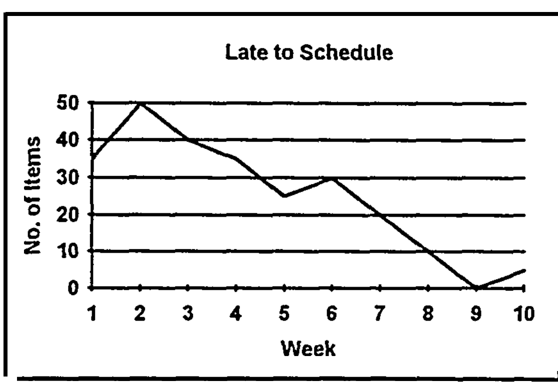


Figure 34
Material Delivered Late - No. of Items

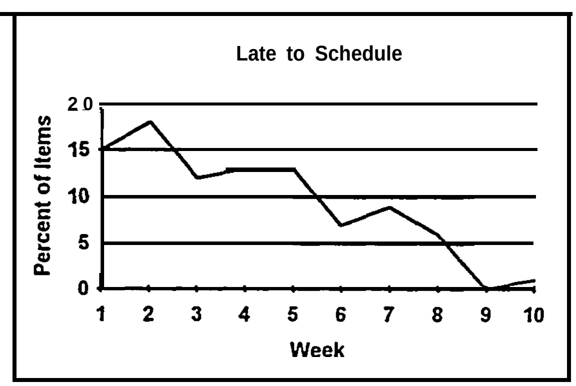


Figure 35
Material Delivered Late - Percent

The analysis of material schedule data is important for the improvement of vendor performance, plan performance, etc. Another method of analyzing the material schedule variances and trends includes tracking the time units that the material is delinquent, as shown in Figure 36. This example shows that 61% of the late material exceeds the required in-yard date by 30 or more days.

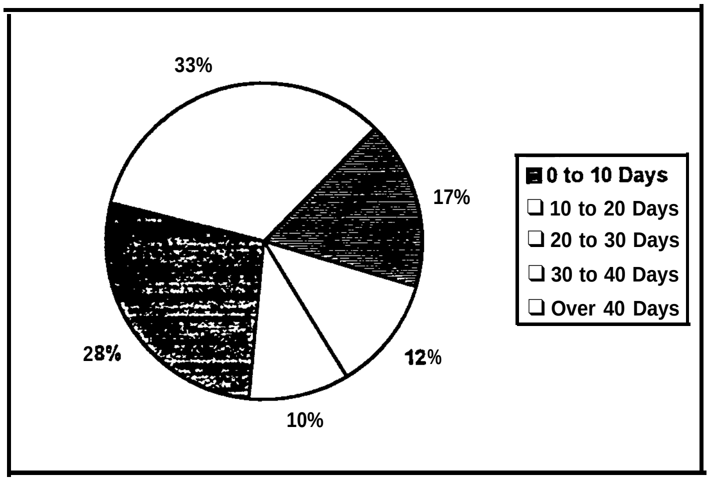


Figure 36
Breakdown of Late Material to Require-in-Yard Date

The causes of late material can be identified and categorized for pareto analysis, as shown in Figure 37. This example indicates that problems occurring in the purchasing area may need further analysis or the development of strategies for process improvement.

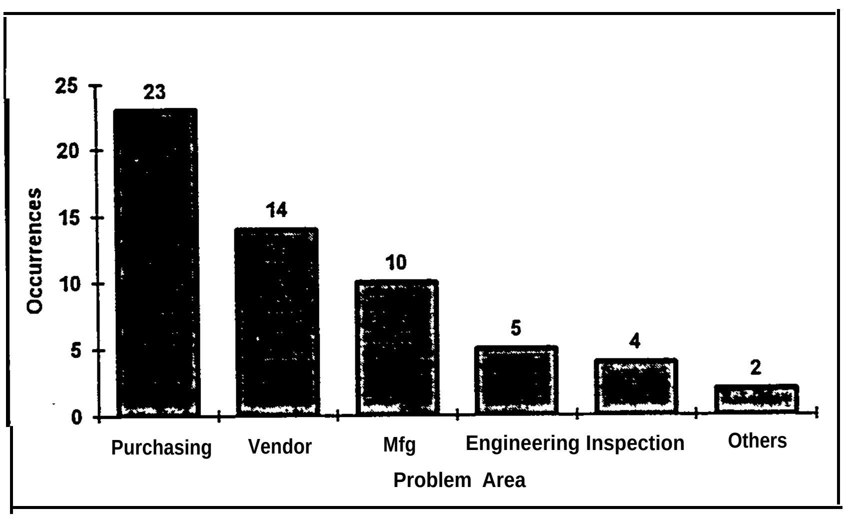


Figure 37
Late Material Pareto Analysis

VI.B.3 Summary of Findings and Results

Changes occurring with PBI's business operations during the project team's case study efforts made it difficult to research detailed material-control-performance measures. Several measures already in use at PBI contained elements of good performance measures. The project team developed examples depicting this data over time. Data presented over time can be used to establish targets, identify variances, and manage both negative and positive trends.

VII. Approach to Implementing New Performance Measures

VII.A.1 Overview

A general approach to implementing performance measures in production and support areas has been developed. The purpose of this guideline is to give the reader a possible, standard, step-by-step process for implementing new performance measures.

APPROACH TO IMPLEMENTING PERFORMANCE MEASURES

1.	Identify reas of possible need for improved performance measures.
2.	Define product and production plan including schedules, budgets, quality requirements, and level of detail necessary.
3.	Examine present methods of performance measurement.
4.	Form team to lead implementation.
5.	Educate team members about performance-measurement methods.
6	Identify specific performance-measurement needs.
/.	Identify alternative methods of performance measurement.
8.	Identify capabilities of information system.
T -	Quantify costs of implementation.
10.	Identify and quantify benefits of implementation.
11.	Develop and initiate implementation plan; including information system changes, labor reporting changes, etc.
12.	Team collects data, develops reports, and analyzes variances.
13.	Initial review of system, identify and implement needed changes.
14.	Make performance measurement system part of everyday life, including continuing education of potential users and others affected by system.
15.	Maintain regular review of measurement system for continuous improvement.

This approach is presented as a guideline for implementing performance measures based on the project team's experience at PBI. This approach cart be modified to meet the needs of your organization.

VII.A.1 Task Descriptions

1. <u>Identifi areas of possible need for immoved Performance measures.</u>

   Since the premise behind performance measurement is the improvement of shipyard processes, initial implementation of these measures should be performed within areas that will benefit most.

   When embarking on your initial performance-measurement effort, some factors and issues to consider include ease of implementing measures, availability of data, and identification of process outputs that are critical to the overall shipbuilding process.

2. <u>Define product and Production plan. including schedules. budgets. quality requirements. and level of detail necessary.</u>

Focus on the outputs or products produced by a process.

Baseline data on the process should be collected to assist in defining the performance measurement needs. These data elements may identify the constraints on process performance (ie. resource constraints, budget errors, scheduling errors, etc.). Planning should be at a level that supports straight-forward progressing and work control.

3. <u>Examine present methods of Performance measurement.</u>

Existing performance measurements should be identified and evaluated. Applicability of existing performance measures will be analyzed and may form the basis for the development of alternative methods. Focus on customer needs and whether or not measures help determine if these needs are being met.

4. <u>Form team to lead implementation.</u>

A team consisting of process operators, supervisors, suppliers, and customers should be formed. These people are not only those that have direct responsibility for the process, but are those that will benefit most from its improvement.

5. <u>Educate team members so that they gain understanding of how measurement methods work and what they mean.</u>

Team members should be exposed to various measurement methods to give them the tools necessary to identify and develop measures that are meaningful. Proper understanding of the goals and methods of performance measurement by all team members will ensure the success of the program.

6. <u>Identify specific performance measurement needs.</u>

The performance-measurement team should determine the critical short- and long- term performance measurement needs of the process.

7. <u>Identify alternative methods of performance measurement.</u>

Identify customer needs, explore all prospects, examine all process characteristics and measurement methodologies.

Also determine the frequency at which the performance data or reports need to be generated. The frequency of generation should be determined by how quickly variations in process performance need to be acted upon.

8. Identify capabilities of Information System.

Determine if existing systems are capable of providing performance data with the data in a format readily usable for measuring performance. Determine the information system tools necessary to generate the desired measures.

9. Quantify costs of implementation.

Examine the costs associated with developing and continued generation of the performance measurements. Costs considerations should be made prior to implementation.

10. Identify and auantify benefits of implementation.

Determine the benefits for measuring the performance of a process. Will the objectives be met? Compare the costs associated with the performance measurement with its benefits.

11. Develop and initiate implementation plan: including information system changes. labor reporting changes. etc.

Develop and initiate a plan for implementing the performance measurements, including all necessary system and procedure changes necessary to generate the proposed performance measures. Assign responsibilities and due dates.

12. Team collects data. develops reports. and analyzes variances.

In many cases the team members are best equipped to generate the performance measures. Allowing the team to take control will establish ownership and job satisfaction for the team members.

13. Initial review of system, identify needed changes.

Review the performance measurements. Are the goals being met? Make necessary changes.

14. Make performance measurement system part of everyday life. including continuing education of potential users and others affected by system.

15. Maintain regular review of measurement system for continuous immovement.

Periodically review the performance measures. Are the goals still being met? At some point changes may be required to meet new or modified team goals. Revise the system as deemed necessary by the users and customers.

Consideration for the above steps will help ensure the success of your effort. In many cases these steps may be performed simultaneously or with some variation in sequence.

VIII. Conclusions

U.S. shipyards have the opportunity to take advantage of many different types of performance measurement, some of which have been discussed in this report. Listed below are some of the most important things that have been learned during this project.

- o Traditional methods of performance measurement, which are usually driven by financial accounting and Navy reporting requirements, and which are ship system-based, are not very useful at the operations level for measuring and improving process performance.

- 0 Accurate and useful measurement of cost, schedule, and productivity performance is completely dependent upon the use of (a) a product work breakdown structure to define work elements, (b) accurate cost and schedule standards (or "targets," or "estimates") for each work element, (c) accurate charging practices, and (d) accurate progressing practices.

- o Shipyards should not hesitate to experiment with performance measurement. If it is felt that some specific type of measurement might be useful, it should be tried. If the method is useful, it can be kept. If it is not useful, or if it becomes unnecessary over time, it can be discontinued.

- o Establishing process measurement trends over time is a fundamental prerequisite to the establishment of an environment of continuous improvement.

- o Shipyards should not ignore or underestimate quality-related costs, especially external failure costs, and should consider establishing and tracking the cost of quality while making the transition from a traditional work environment to an environment of continuous improvement.

- o Sometimes the best way to begin to determine what types of performance measurement might be useful for improving a particular process is to ask "Who are the customers (external and/or internal) using the product of this process, " and, "What do the customers want of this product. " Quality Function Deployment (QFD) can be tremendously useful as a tool for helping to identify customer requirements, product characteristics, and associated performance measures.

- o Although a particular new performance measurement methodology may represent a straightforward and correct technical approach toward helping to improve a particular process, the implementation of this new methodology may prove to be very difficult. In implementing any kind of change, human and cultural issues, such as insecurity that can result from unfamiliarity with something new, are at least as important as technical issues and must be dealt with at the same time. Strong leadership, appropriate education at all levels, and recognition for participation and success are vital to the successful implementation of new performance measurement methodologies.

- o Performance measurement methods can significantly affect behavior and should be designed to encourage behavior conducive to process improvement.
- o The purpose of each performance measurement should be stated clearly and should remain consistent. If a company designs and implements a certain performance measurement for the stated purpose of measuring and improving a specific process, and then uses the resulting data to attempt to judge worker performance, the performance measurement system will fail.
- o It is difficult to establish performance measures for support areas of shipyards because the products of their operations are usually not as easy to define as those of production operations.

In the short period of time that PBI had to experiment with different performance measurement methods as a part of this research project, reasonable productivity performance was established for surface preparation and coating in different types of spaces. These productivity data can now be used for establishing better cost estimates for similar work elements in the future, for bidding on new contracts, and as a baseline for process improvement. The usefulness of cost and schedule performance data generated in these production areas was limited, because there were no formal standards or targets previously established at the interim product level to use as a baseline. Therefore, any cost and schedule variances generated were of questionable value. However, now that baseline productivity has been established for these production processes, future cost and schedule performance measurement will be much more meaningful.

In the support area of material control, PBI found that it was much more difficult to clearly identify specific products. They found that an appropriate approach to establishing performance measures was to attempt to identify the customers of this support area, and to establish what products or services, and what product and service characteristics, these customers wanted from the material control support area. From this experience, it became clear that it is more difficult to establish performance measures for support areas than for production areas.

The **Approach to Implementing New Performance Measures** evolved from research in performance measurement implementation in shipyards and other industries, and from PBI's experience with this project. The approach outlined is intended to be a general guideline for implementing new performance measurement methods. Individual shipyards may wish to modify the implementation process to suit their own needs. However, the importance of education in this process at all levels of the organization cannot be underestimated. The more informed all participants and users of performance measurement are, the easier it will be to manage the changes that are inherent and necessary in creating and sustaining an environment of continuous improvement.

IX. Appendices

Appendix A

Survey Results - Detailed Worksheets

Question #1

New Construction Shipyard

	A	B	C	D	E	F	Avg	10-Avg
Marketing	1	1	1		1	2	1.2	8.8
Contracts	1	1	1		5	5	2.6	7.4
Human Res.	1	4	1		3	10	3.8	6.2
Training	1	2	1		3	5	2.4	7.6
Accounting	1	1	1			8	2.8	7.3
Finance	1	1	1		2	9	2.8	7.2
Legal Affairs	1	1	1				1.0	9.0
Design Eng.	6	5	5		7	5	5.6	4.4
Prod. Eng.	7	8	5		5	4	5.8	4.2
Prod. Control	8	1	5		5	7	5.2	4.8
Purchasing	1	1	1		5	7	3.0	7.0
Mat'l Control	1	1	1		5	6	2.8	7.2
Cmptr. Sys.	1	5	1		8	7	4.4	5.6
Telecom. Sys	1	1	1		8	4	3.0	7.0
Man./Ind. Eng.	7	1	5		4	4	4.2	5.8
Facil. Eng.	1	2	5		7	4	3.8	6.2
Facil. Maint.	1	1	1		7	8	3.6	6.4
QA/QC	8	1	5		5	1	4.0	6.0
Labor Relat.	1	6	1		6		3.5	6.5
Pub. Relat.	1	1	1		3	2	1.6	8.4
Safety/Health	1	1	1		5	6	2.8	7.2
Welding Eng.		1	5		7	2	3.8	6.3
Cost Eng.	1	9	5		4	3	4.4	5.6
Trades Admin.		1	1			1	1.0	9.0
Envir. Eng.		1	4			10	5.0	5.0
Printing/Pub.	1	1	1			6	2.3	7.8
Tool Support		1	1		5	6	3.3	6.8
Progrm Mng.						3	3.0	7.0
Custmr. Relat.						3	3.0	7.0

Question #1

Repair Shipyard

	A	B	C	D	Avg	10-Avg
Marketing	6	8		5	6.3	3.7
Contracts	4	7		6	5.7	4.3
Human Res.	6	8		7	7.0	3.0
Training		9		4	6.5	3.5
Accounting	8	8		4	6.7	3.3
Finance	9	8		4	7.0	3.0
Legal Affairs	9	8			8.5	1.5
Design Eng.						
Prod. Eng.	8	7		7	7.3	2.7
Prod. Control	8	8		7	7.7	2.3
Purchasing	6	7	6	4	5.8	4.3
Mat'l Control	6	8		6	6.7	3.3
Cmptr. Sys.		8		7	7.5	2.5
Telecom. Sys	6	8		7	7.0	3.0
Man./Ind. Eng.	6	7		3	5.3	4.7
Facil. Eng.	5	8		7	6.7	3.3
Facil. Maint.	5	8		5	6.0	4.0
QA/QC	6	8		4	6.0	4.0
Labor Relat.	8	7		3	6.0	4.0
Pub. Relat.	8	9		3	6.7	3.3
Safety/Health	6	10		7	7.7	2.3
Welding Eng.		8		7	7.5	2.5
Cost Eng.	8	7		5	6.7	3.3
Trades Admin.				4	4.0	6.0
Envir. Eng.		9		3	6.0	4.0
Printing/Pub.						
Tool Support				6	6.0	4.0
Progrm Mng.						
Custmr. Relat.						

Question #1

Public Shipyard

	A	B	Avg	10-Avg
Marketing	6	3	4.5	5.5
Contracts	6	5	5.5	4.5
Human Res.	5	5	5.0	5.0
Training	6	5	5.5	4.5
Accounting	8	5	6.5	3.5
Finance	8	5	6.5	3.5
Legal Affairs	2	5	3.5	6.5
Design Eng.	8	1	4.5	5.5
Prod. Eng.	8	5	6.5	3.5
Prod. Control	7	3	5.0	5.0
Purchasing	4	5	4.5	5.5
Mat'l Control	6	3	4.5	5.5
Cmptr. Sys.	8	3	5.5	4.5
Telecom. Sys	8	3	5.5	4.5
Man./Ind. Eng.	8	5	6.5	3.5
Facil. Eng.	7	5	6.0	4.0
Facil. Maint.	5	5	5.0	5.0
QA/QC	7	6	6.5	3.5
Labor Relat.	4	3	3.5	6.5
Pub. Relat.	5	3	4.0	6.0
Safety/Health	4	6	5.0	5.0
Welding Eng.	7	2	4.5	5.5
Cost Eng.	7	1	4.0	6.0
Trades Admin.	4	1	2.5	7.5
Envir. Eng.	6	6	6.0	4.0
Printing/Pub.	5	2	3.5	6.5
Tool Support	7	3	5.0	5.0
Progrm Mng.				
Custmr. Relat.				

Question #1

Totals

	Avg	10-Avg
Marketing	3.4	6.6
Contracts	4.1	5.9
Human Res.	5.0	5.0
Training	4.0	6.0
Accounting	4.9	5.1
Finance	4.8	5.2
Legal Affairs	3.9	6.1
Design Eng.	5.3	4.7
Prod. Eng.	6.4	3.6
Prod. Control	5.9	4.1
Purchasing	4.3	5.7
Mat'l Control	4.3	5.7
Cmptr. Sys.	5.3	4.7
Telecom. Sys	4.7	5.3
Man./Ind. Eng.	5.0	5.0
Facil. Eng.	5.1	4.9
Facil. Maint.	4.6	5.4
QA/QC	5.1	4.9
Labor Relat.	4.3	5.7
Pub. Relat.	3.6	6.4
Safety/Health	4.7	5.3
Welding Eng.	4.9	5.1
Cost Eng.	5.0	5.0
Trades Admin.	2.0	8.0
Envir. Eng.	5.6	4.4
Printing/Pub.	2.7	7.3
Tool Support	4.1	5.9
Progrm Mng.	3.0	7.0
Custmr. Relat.	3.0	7.0

Question #2

New Construction Shipyard

	A	B	C	D	E	F	Avg	Wgt Scr	Rank
Marketing	8	7	8		10	10	8.6	75.7	1
Contracts	10	6	10		8	8	8.8	65.1	3
Human Res.	10	8	8		8	6	5.0	49.6	15
Training	8	9	9		8	7	8.2	62.3	5
Accounting	7	9	7			7	7.5	54.4	10
Finance	8	8	7		10	6	7.8	56.2	7
Legal Affairs	7	8	6				7.0	63.0	4
Design Eng.	9	8	7		10	10	8.8	38.7	25
Prod. Eng.	10	9	7		10	9	9.0	37.8	26
Prod. Control	7	9	7		10	8	8.2	39.4	24
Purchasing	9	8	7		5	10	7.8	54.6	9
Mat'l Control	9	6	7		5	9	7.6	54.7	8
Cmptr. Sys.	8	10	7		5	10	8.0	44.8	20
Telecom. Sys	6	9	7		5	9	7.2	50.4	14
Man./Ind. Eng.	8	5	5		8	10	7.2	41.8	21
Facil. Eng.	7	6	6		5	8	6.4	39.7	23
Facil. Maint.	7	6	7		5	10	7.0	44.8	20
QA/QC	10	9	8			7	8.5	51.0	13
Labor Relat.	10	10	9		8		9.3	60.1	6
Pub. Relat.	8	9	7		5	3	6.4	53.8	11
Safety/Health	10	10	9		8	10	9.4	67.7	2
Welding Eng.		9	7		5	10	7.8	48.4	16
Cost Eng.	10	10	6		5	9	8.0	44.8	20
Trades Admin.		2	7			8	5.7	51.0	13
Envir. Eng.		5	7			9	7.0	35.0	27
Printing/Pub.	8	1	6			6	5.3	40.7	22
Tool Support		8	8		5	6	6.8	45.6	17
Progrm Mng.									
Custmr. Relat.									

Question #2

Repair Shipyard

	A	B	C	D	Avg	Wgt Scr	Rank
Marketing	10	10	1	8	7.3	26.6	12
Contracts	2	8	9	9	7.0	30.3	5
Human Res.	9	8	9	9	8.8	26.3	13
Training		9	9	8	8.7	30.3	5
Accounting	10	9	8	7	8.5	28.3	7
Finance	10	9	6	8	8.3	24.8	16
Legal Affairs	9	7	6	7	7.3	10.9	25
Design Eng.			1	4	2.5		27
Prod. Eng.	8	8	9	9	8.5	22.7	18
Prod. Control	10	9	8	8	8.8	20.7	22
Purchasing	8	9	9	9	9.8	37.2	1
Mat'l Control	6	9	8	8	7.8	25.8	14
Cmptr. Sys.		8	6	7	7.0	17.5	24
Telecom. Sys	9	9	5	7	7.5	22.5	19
Man./Ind. Eng.	8	8	8	4	7.0	32.7	37
Facil. Eng.	5	9	7	7	7.0	23.3	17
Facil. Maint.	5	9	8	8	7.5	30.0	6
QA/QC	5	9	5	8	7.0	26.0	10
Labor Relat.	8	10	9	8	8.8	35.0	2
Pub. Relat.	9	6	6	5	6.5	21.7	20
Safety/Health	10	10	8	9	9.3	21.6	21
Welding Eng.		9	8	5	7.3	18.3	23
Cost Eng.	10	9	4	7	7.5	25.0	15
Trades Admin.			3	6	4.5	27.0	11
Envir. Eng.	10	9	2	7	7.0	28.0	10
Printing/Pub.		8	2	5	5.0		27
Tool Support			8	6	7.0	28.0	10
Progrm Mng.							
Custmr. Relat.							

Question #2

Public Shipyard

	A	B	C	Avg	Wgt Scr	Rank
Marketing	9	1	5	5.0	27.5	10
Contracts	9	3	6	6.0	27.0	12
Human Res.	9	6	10	8.3	41.7	2
Training	7	7	5	6.3	28.5	7
Accounting	7	3	7	5.7	19.8	19
Finance	7	3		5.0	17.5	21
Legal Affairs	3	3	1	2.3	15.2	24
Design Eng.	9	3	10	7.3	40.3	3
Prod. Eng.	8	3	10	7.0	24.5	16
Prod. Control	7	3	8	6.0	30.0	6
Purchasing	9	5	10	8.0	44.0	1
Mat'l Control	7	3	10	6.7	36.7	4
Cmptr. Sys.	5	1	3	3.0	13.5	25
Telecom. Sys	7	1	3	3.7	16.5	22
Man./Ind. Eng.	8	1	5	4.7	16.3	23
Facil. Eng.	8	5	6	6.3	25.3	15
Facil. Maint.	8	5	6	6.3	31.7	5
QA/QC	8	7	7	7.3	25.7	14
Labor Relat.	3	1	7	3.7	23.8	17
Pub. Relat.	2	1	3	2.0	12.0	26
Safety/Health	4	7	6	5.7	28.3	8
Welding Eng.	9	1	5	5.0	27.5	10
Cost Eng.	8	1		4.5	27.0	12
Trades Admin.	2	1		1.5	11.3	27
Envir. Eng.	4	3	7	4.7	18.7	20
Printing/Pub.	7	2	3	4.0	26.0	13
Tool Support	8	1	3	4.0	20.0	18
Progrm Mng.						
Custmr. Relat.						

Question #2

Totals

	Avg	Wgt Scr	Rank
Marketing	7.3	47.9	1
Contracts	7.5	44.3	5
Human Res.	8.3	41.7	7
Training	7.8	46.9	2
Accounting	7.4	37.6	10
Finance	7.5	38.8	8
Legal Affairs	5.7	35.0	14
Design Eng.	7.1	33.5	19
Prod. Eng.	8.3	30.0	24
Prod. Control	7.8	32.1	23
Purchasing	8.2	46.8	3
Mat'l Control	7.4	42.3	6
Cmptr. Sys.	6.4	29.7	25
Telecom. Sys	6.4	34.0	18
Man./Ind. Eng.	6.5	32.5	21
Facil. Eng.	6.6	32.3	22
Facil. Maint.	7.0	37.8	9
QA/QC	7.6	37.4	11
Labor Relat.	7.5	42.8	5
Pub. Relat.	5.3	34.1	17
Safety/Health	8.4	44.6	4
Welding Eng.	6.8	34.9	15
Cost Eng.	7.2	35.9	12
Trades Admin.	4.1	33.1	20
Envir. Eng.	8.3	27.9	26
Printing/Pub.	4.8	35.2	13
Tool Support	5.9	34.5	16
Progrm Mng.			
Custmr. Relat.			

Question #7

New Construction Shipyard

	A	B	C	D	E	F	Avg	10-Avg
Struc. Manuf.	10	7	7	8	5	4	6.8	3.2
Pipe Manuf.	8	6	7	8	5	4	6.3	3.7
Sheet Metal	8	2	1	8	5	4	4.7	5.3
Ele. Manuf.	7	5	7	6	3	4	5.3	4.7
Machine Shop	7	7	7	8	3	4	6.0	4.0
Foundry								
Blast, Paint	9	1	7	6	1	4	4.7	5.3
On-Unit	7	7	7	8	1		5.0	5.0
On-Block	7	8		8	1		6.0	4.0
On-Board	9	7	7	8	5		7.2	2.8
Inspec., Test	10	7	6	5	5	4	6.2	3.8
Riggers	8	3	7	5	1	4	4.7	5.3
Temp. Services	7	3	1	5	1	4	3.5	6.5
Cleaning	6	3	1	5	1	4	3.7	6.3

Repair Shipyard

	A	B	C	D	Avg	10-Avg
Struc. Manuf.				8	8.0	2.0
Pipe Manuf.				7	7.0	3.0
Sheet Metal				7	7.0	3.0
Ele. Manuf.				7	7.0	3.0
Machine Shop				6	6.0	4.0
Foundry						
Blast, Paint				9	9.0	1.0
On-Unit				8	8.0	2.0
On-Block				8	8.0	2.0
On-Board				8	8.0	2.0
Inspec., Test				1	1.0	9.0
Riggers				4	4.0	6.0
Temp. Services				4	4.0	6.0
Cleaning				2	2.0	8.0

Question #7

Public Shipyard

	A	B	C	Avg	10-Avg
Struc. Manuf.	7			7.0	3.0
Pipe Manuf.	7			7.0	3.0
Sheet Metal	7			7.0	3.0
Ele. Manuf.	7			7.0	3.0
Machine Shop	7			7.0	3.0
Foundry	6			6.0	4.0
Blast, Paint	8			8.0	2.0
On-Unit	7			7.0	3.0
On-Block	7			7.0	3.0
On-Board	7			7.0	3.0
Inspec., Test	7			7.0	3.0
Riggers	6			6.0	4.0
Temp. Services	7			7.0	3.0
Cleaning	5			5.0	5.0

Totals

	Avg	Wgt Scr
Struc. Manuf.	7	3.0
Pipe Manuf.	6.5	3.5
Sheet Metal	5.3	4.8
Ele. Manuf.	5.8	4.3
Machine Shop	6.1	3.9
Foundry	6.0	4.0
Blast, Paint	5.6	4.4
On-Unit	5.6	4.4
On-Block	6.5	3.5
On-Board	7.3	2.7
Inspec., Test	5.6	4.4
Riggers	4.8	5.3
Temp. Services	4.0	6.0
Cleaning	3.6	6.4

Question #8

New Construction Shipyard

	A	B	C	D	E	F	Avg	Wgt Scr	Rank
Struc. Manuf.	10	9	8	10	10	10	9.5	30.1	12
Pipe Manuf.	8	8	8	8	8	10	8.3	30.6	11
Sheet Metal	8	2	8	7	8	9	7.0	37.3	6
Ele. Manuf.	9	6	8	8	8	10	8.2	38.1	5
Machine Shop	8	8	8	7	8	9	8.0	32.0	9
Foundry									
Blast, Paint	10	8	8	10	8	10	9.0	48.0	1
On-Unit	7	8	8	10	10		8.6	43.0	2
On-Block		9	8	10	10		8.8	35.2	8
On-Board	79	8	8	10	10		9.0	25.2	13
Inspec., Test	10	8	7	8	10	7	8.3	31.9	10
Riggers	8	5	8	8	4	7	6.7	35.6	7
Temp. Services	8	5	6	8	4	8	6.5	42.3	3
Cleaning	8	3	7	8	4	8	6.3	40.1	4

Repair Shipyard

	A	B	C	D	Avg	Wgt Scr	Rank
Struc. Manuf.				9	9.0	18.0	10
Pipe Manuf.				9	9.0	27.0	8
Sheet Metal				9	9.0	27.0	8
Ele. Manuf.				9	9.0	27.0	8
Machine Shop				9	9.0	36.0	5
Foundry							
Blast, Paint				9	9.0	9.0	13
On-Unit				7	7.0	14.0	12
On-Block				7	7.0	14.0	12
On-Board				9	9.0	18.0	10
Inspec., Test				7	7.0	63.0	1
Riggers				8	8.0	48.0	3
Temp. Services				8	8.0	48.0	3
Cleaning				5	5.0	40.0	4

Question #8

Public Shipyard

	A	B	C	Avg	Wgt Scr	Rank
Struc. Manuf.	10		10	10.0	30.0	5
Pipe Manuf.	10		10	10.0	30.0	5
Sheet Metal	10		10	10.0	30.0	5
Ele. Manuf.	10		10	10.0	30.0	5
Machine Shop	10		10	10.0	30.0	5
Foundry	7			7.0	28.0	6
Blast, Paint	9		5	7.0	14.0	14
O -U						
On-B ck						
On-Board	8		10	9.0	27.0	7
Inspec., Test	8		5	6.5	19.5	13
Riggers	8		5	6.5	26.0	8
Temp. Services	8		5	6.5	19.5	13
Cleaning	5		5	5.0	25.0	9

Totals

	Avg	Wgt Scr	Rank
Struc. Manuf.	9.6	28.7	11
Pipe Manuf.	8.8	30.7	10
Sheet Metal	8.9	42.2	1
Ele. Manuf.	8.7	36.8	5
Machine Shop	8.6	33.2	9
Foundrv	7.0	28.0	13
Blast, Paint	8.6	37.4	4
On-Unit	8.3	36.3	6
On-Block	8.0	28.0	13
On-Board	9.0	24.4	14
Inspec.. Test	7.8	34.0	8
Riggers	6.8	35.6	7
Temp. Services	6.7	40.0	2
Cleaning	5.9	37.5	3

Summary

	New Con. Rank	Repair Rank	Public Rank	Overall Rank	Wgt. Score
Marketing	1	12	10	1	47.9
Contracts	3	5	12	5	44.3
Human Res.	15	13	2	8	41.7
Training	5	5	7	2	46.9
Accounting	10	7	19	11	37.6
Finance	7	16	21	9	38.8
Legal Affairs	4	25	24	15	35.0
Design Eng.	25	27	3	20	33.5
Prod. Eng.	26	18	16	25	30.0
Prod. Control	24	22	6	24	32.1
Purchasing	9	1	1	3	46.8
Mat'l Control	8	14	4	7	42.3
Cmptr. Sys.	20	24	25	26	29.7
Telecom. Sys	14	19	22	19	34.0
Man./Ind. Eng.	21	37	23	22	32.5
Facil. Eng.	23	17	15	23	32.3
Facil. Maint.	20	6	5	10	37.8
QA/QC	13	10	14	12	37.4
Labor Relat.	6	2	17	6	42.8
Pub. Relat.	11	20	26	18	34.1
Safety/Health	2	21	8	4	44.6
Welding Eng.	16	23	10	16	34.9
Cost Eng.	20	15	12	13	35.9
Trades Admin.	13	11	27	21	33.1
Envir. Eng.	27	10	20	27	27.9
Printing/Pub.	22	27	13	14	35.2
Tool Support	17	10	18	17	34.5
Progrm Mng.					
Custmr. Relat.					

	New Con. Rank	Repair Rank	Public Rank	Overall Rank	Wgt. Score
Struc. Manuf.	12	10	5	11	28.7
Pipe Manuf.	11	8	5	10	30.7
Sheet Metal	6	8	5	1	42.2
Ele. Manuf.	5	8	5	5	36.8
Machine Shop	9	5	5	9	33.2
Foundry			6	12	28.0
Blast, Paint	1	13	14	4	37.4
On-Unit	2	12	10	6	36.3
On-Block	8	12	13	12	28.0
On-Board	13	10	7	13	24.4
Inspec., Test	10	1	13	8	34.0
Riggers	7	3	8	7	35.6
Temp. Services	3	3	13	2	40.0
Cleaning	4	4	9	3	37.5

Appendix B

Paraphrases of Answers to Narrative Survey Questions

3) Briefly identify/describe the methods that are used by your shipyard to measure the performance of each shipbuilding support area with a score of 8 or greater in Question 2.

-Logic.
-Subjective.
-DOD type cost schedule control system (CSCS).
-Estimated vs. spent.
-# of accidents.
-User complaints.
-Computer system % available on-line time, user response time, up-time.
-Elapsed time for P.O. placement.
-Billing turnaround time.
-Accounts receivable balance.
-Accounts payable discounts taken.
-Inventory accuracy.
-Progress vs. availability.
-Bottom line profit.
-# of jobs bid.
-Timeliness of bid to award.
-Speed and accuracy of inspections.
-# of cost savings ideas implemented.

4) Briefly identify/describe the methods that are used by your shipyard to measure overall performance of support areas.

-Subjective.
-Variance measurement against standards.
-Cost/benefit analysis.
-Reactive and crude analysis of late work only.
-Bid vs. budgets vs. actual labor hours.
-Employee turnover, absenteeism.
-Schedule variances.
-CSCS.
-Regular meetings between production and support management.

5) How effective and useful are these methods that are used to measure the *overall* performance of support areas?

-Don't know.
-Very good, but don't use the derived information to effect meaningful improvement.
-Good analysis of past history, but nothing for process improvement.
-Very useless.
-Not very.
-Mostly effective.
-Not very appropriate.
-Very good.
-Not very; too general.

6) In general, have the performance measurement methods used in your shipyard's support areas evolved from internal customer needs or external customer requirements?

-Mostly internal, except for areas with external customer interface.
-External.
-External, but not very meaningful.
-Both.
-Mostly external, but need more internal.
-Internal.
-Neither; it is impossible to get good measures this way because of prejudiced input.
-Performance measures profitability, not related to customers

9) Briefly identify/describe the methods that are used by your shipyard to measure the performance of each shipbuilding production area with a score of ~ or greater in Question (8).

-Work package progressing, with schedule variance to milestones.
-Estimate vs. actual labor hours.
-Estimated vs. actual time.
-Measure of rework.
-Schedule variance.
-Inspection to QA standards.
-Variance to craft and operation-specific standards.
-Crude attempts to monitor changes and rework.
-Work completed per shift.
-Process variance.

10) Briefly identify/describe the methods that are used by your shipyard to measure overall Performance of production areas.

-Cost schedule control system and CPM.
-Cost and schedule variance.
-CSCS, CSSR
-Overall quality and utility of finished product.
-Earned standard hours vs. actual hours, from work package level to cost center or ship level.
-Only look at areas which are “over budget” or “late.”
-Rework hours vs. “normal” rework hours.
-Summaries of CSCS data by type of work, key event, trade, contract.

11) How effective and useful are these methods that are used to measure the overall performance of moduction areas?

-Don’t know.
-Good.
-Effective because of management emphasis.
-Pure hindsight, no measures for process improvement.
-Only a start; not precise or timely.
-Fairly good.

12) In general, have the performance measurement methods used in your shipyard’s production areas evolved from internal customer needs or external customer requirements?

-CSCS and CPM network are required by external customer contract.
-External.
-Internal and external.
-External but relatively useless.
-Both.
-Internal- profit motive.
-Performance measurement as we use it measures income and profitability; it is not strongly based on the customer.

13) Briefly identify/describe the methods that are used by your shipyard to measure <u>overall shipyard performance</u>.

-Budget performance and variance analysis; adherence to financial business plan.
-End of year profit and loss figures.
-Reactive, looking at budget and schedule problems after they occur.
-Bid cost vs. actual and estimated.
-Macro schedule variance to milestones.
-Normal financial measures on financial statements.
-(Sales-material costs)/labor costs> 2 if possible; goal is to double labor costs as a percentage of sales.
-Overall productivity relative to sales.
-On-time and on-budget delivery.

14) How effective and useful are these methods that are used to measure the <u>overall performance of your shipyard</u>?

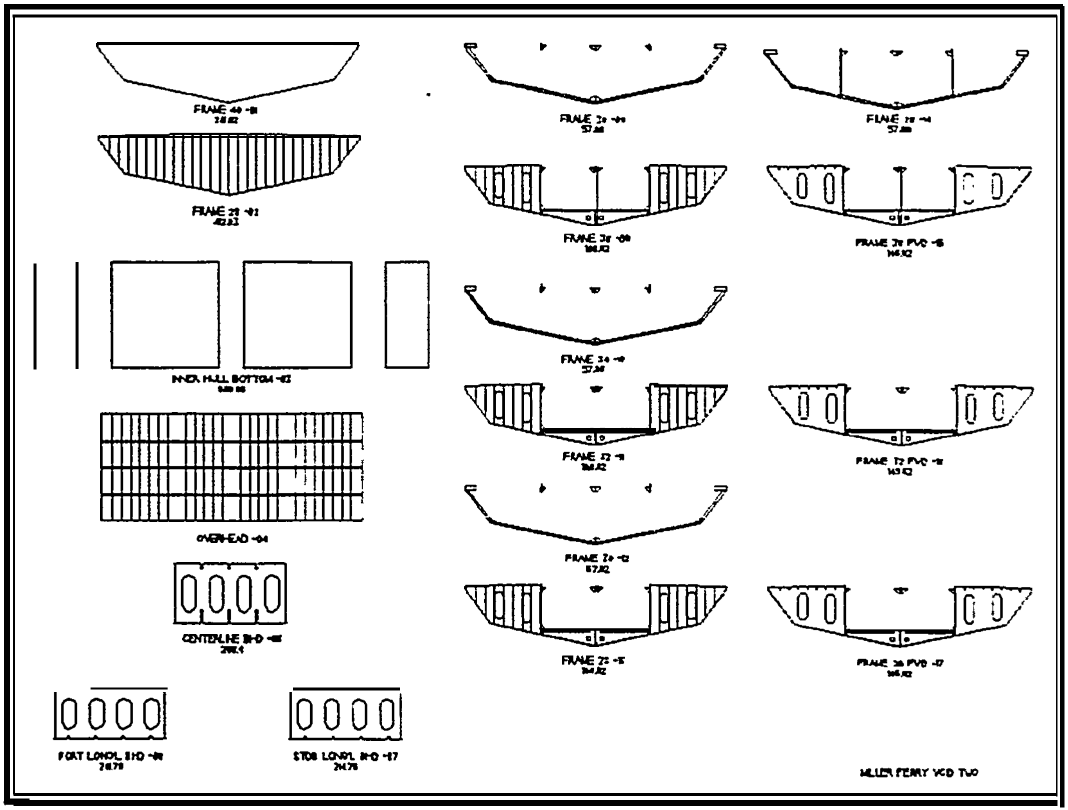
-Unknown.
-Good.
-As good as the people and groups supporting the system
-Outside of Navy work, market share should be used as the performance measure.
-Not very effective to somewhat effective.
-Excellent.
-Fairly accurate.

15) If internal customer needs are a significant factor underlying <u>any</u> of your performance measurement methods, what formal methods, if any, have been established within your shipyard to identify these internal customer needs?

-None, but improving system to include internal customer input.
-None.
-None, but we are starting a TQM initiative.
-The only internal customer need is profit on each job.
-The implementation of TQM is important to get each craft and department involved in improvement; performance measurement is not as important as performance improvement. Most things are unmeasurable anyway.
-None are formally established.
-Quality training.
-Weekly meetings.

Appendix C

Sq.Ft. CAD Representation



Sq.Ft. Calculations

Part I.D.	Sq.Ft.	Paint System No.	Number of Coats	Painted Sq.Ft.
Void2-02	412.03	5	2	824.06
Void2-03	696.88	5	2	1393.76
Void2-04	1026.22	5	2	2052.44
Void2-05	266.40	5	2	532.80
Void2-06	241.78	5	2	483.56
Void2-07	214.78	5	2	429.56
Void2-08	57.99	5	2	115.98
Void2-09	188.92	5	2	377.84
Void2-10	57.99	5	2	115.98
Void2-11	188.92	5	2	377.84
Void2-12	57.92	5	2	115.84
Void2-13	188.92	5	2	377.84
Void2-14	57.99	5	2	115.98
Void2-15	145.62	5	2	291.24
Void2-16	145.82	5	2	291.64
Void2-17	145.82	5	2	291.64
Totals	4094.00			8188.00

Appendix D
Paint Shop Labor Codes - JSAD

Operation Codes

CA = Cleanup Abrasive	EQ = EQuip s/t sur prep	MH = Matrl Handling	ST = Stenciling
CK = CattlK butts 8C seams	FS = Fill holeS	PB = Brush Paint	TP = TaPe
CL = CLean	GB = Glass Bead	SP = Spray Paint	UT = UnTape
DC = apply Deck Covering	GR = Grind	SB = Sand Blast	Zs = Zipstrip
EP = Equip s/t Paint	LT = Lost Time	SD = SanD	OR = OtheR - commem

Abnormal Time Codes

DI = Dirty	FE = Faulty Equipment	TR = TRade interference	OR = OtheR - commem
EL = Equip. Left behind	PM = Poor quality MIrl.	WT = WeaTH%er - explain	
ER = Equip. Removed	PS = Painted out of Seq.	WR = Work Rescheduled	

Lost Time Codes

AI = Additional Instruction	EM = Equip. Maltinction	TR = TRade interference	OR = OtheR - comment
AM = Additional Mtrl.	ER = Equip. being Repaired	WT = Weallter - explain	

Rework Codes

TR = TRades	1P = Improper Prepaation	PM = Poor quality MM.	PS = Paint out of Seq.
1A = Improper Application	FE = Faulty Equipment	WT = WeaTher - explain	OR = OrheR - comment

Sample Paint Time Card - JSAD

Line 1: Normal Operations
When performing work that is considered normal, select the two digit code from the list of Operation Codes: Enter the two digit code in the Hull # field on the time card. (Example - normal sand blast operations “SB. ”)

Line 2: Abnormal Conditions
When performing an operation that is influenced by an abnormal condition, select the two digit code from the list of Operation Codes for the operation being performed and select the two digit code from the list of Abnormal Time Codes for the abnormal condition. Enter the four digits in the Hull # field with the Operation Code first, followed by the Abnormal Time Code. (Example - sand blast operations affected by faulty equipment “SBFE. ”)

Line 3: Lost Time
When work can not continue because of a lost time condition, select the two digit code “LT” from the list of Operation Codes and select the two digit code from the list of Lost Time Codes for the lost time condition. Enter the four digits in the Hull # field with “LT” first, followed by the Lost Time Code. (Example - lost time caused by equipment being repaired “LTER. ”)

Line 4: Rework
When performing rework, select the two digit code from the list of Operation Codes for the operation being performed and select the two digit code from the list of Rework Codes for the cause of rework. Enter the four digits in the Hull # field with the Operation Code first, followed by the Rework Code and place an “R” in the Rework field. (Example - rework spray painting operations caused by poor quality material, “SPPM” in the Hull # field and “R” in the Rework field.)

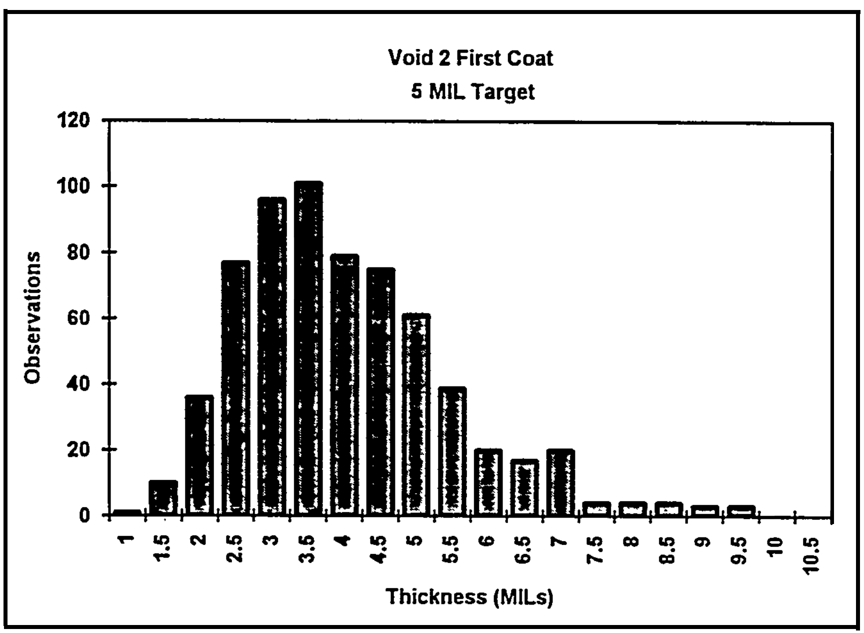
	CONT. #	HULL #	WORK ORDER #	REG. HRS.	O.T. HRS.	REW	DP
Line 1	9999	SB	999	3			
Line 2	9999	SBFE	999	.5			
Line 3	9999	LTER	999	1			
Line 4	9999	SPPM	999	2		R	

Appendix E

Quality Performance - Coating Thickness

Void 2- First Coat MIL Readings -5 MIL Target

MIL	Frequency
1.0	1
1.5	10
2.0	36
2.5	77
3.0	96
3.5	101
4.0	79
4.5	75
5.0	61
5.5	39
6.0	20
6.5	17
7.0	20
7.5	4
8.0	4
8.5	4
9.0	3
9.5	3
10.0	0
10.5	0



Target = 5 MILs
Mean = 4.0 MILs
Stdv = 1.5 MILs
3 Stdv = 4.5 MILs
High = 9.5 MILs
Low = 1.0 MILs

Appendix F

Applying Coating in Excess of Required Thicknesses

Amount of Coating Required to Coat 47,000 Sq.Ft.

Based on Existing Process Variation, Assumptions are:

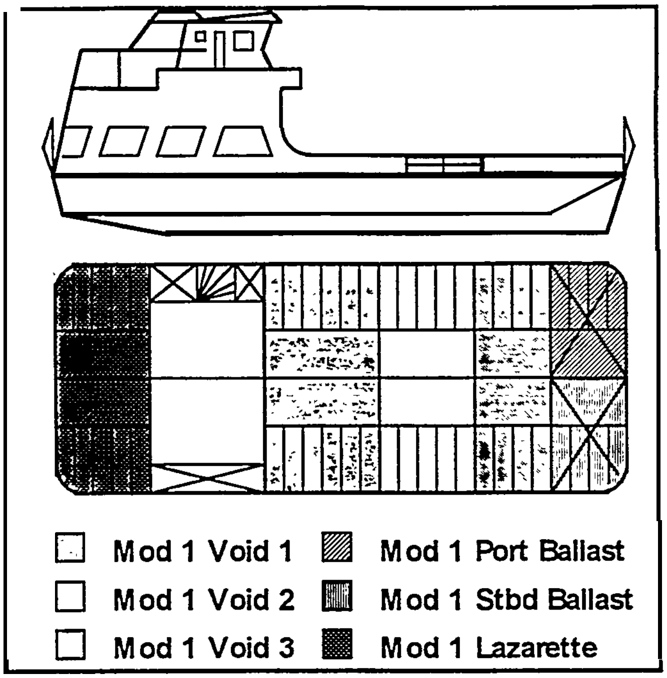
1. 1605 Sq.Ft. Coverage 1 MIL Thick for 100% Solids
2. 30% Loss Due to Overspray and Cleanup
3. 65% Solids Coating
4. Does Not Include Supervision or Material Handling Labor

Target Thickness in MILs 10
Cost of Coating per Gal. *$28*
Cost of Labor per Hour *$16*
Gallons Sprayed per Hour *2.4*

Ave. MILs (+)	Gallons	Matrl Cost	Labor	Labor Cost	Total Cost	Diff. in Cost
0	643.6	$18,021	268.2	$4,291	$22,312	
1	708.0	$19,823	295.0	$4,720	$24,543	$2,231
2	**772.3**	**$21,625**	**321.8**	**$5,149**	**$26,774**	**$4,462**
3	836.7	$23,427	348.6	$5,578	$29,005	$6,693
4	901.0	$25,229	375.4	$6,007	$31,236	$8,924
5	965.4	$27,031	402.2	$6,436	$33,467	$11,155
6	1029.7	$28,833	429.1	$6,865	$35,698	$13,386
7	1094.1	$30,635	455.9	$7,294	$37,929	$15,617
8	1158.5	$32,437	482.7	$7,723	$40,160	$17,848
9	1222.8	$34,239	509.5	$8,152	$42,391	$20,079
10	1287.2	$36,041	536.3	$8,581	$44,622	$22,310

Appendix G

Miller Ferry-Performance Report
Mod 1 Voids, Ballast Tanks, and Lazarette
Week Ending - #5



Summary

Charge Numbers
- 1501- Voids
- 1502- Ballast Tanks
- 1503- Lazarette

Square Footage - Surface Preparation
- Voids = 10000
- Ballast Tanks = 8000
- Lazarette = 6000
- Total = 24000

Square Footage - Surface Coating
- Voids = 20000
- Ballast Tanks = 16000
- Lazarette = 12000
- Total = 48000

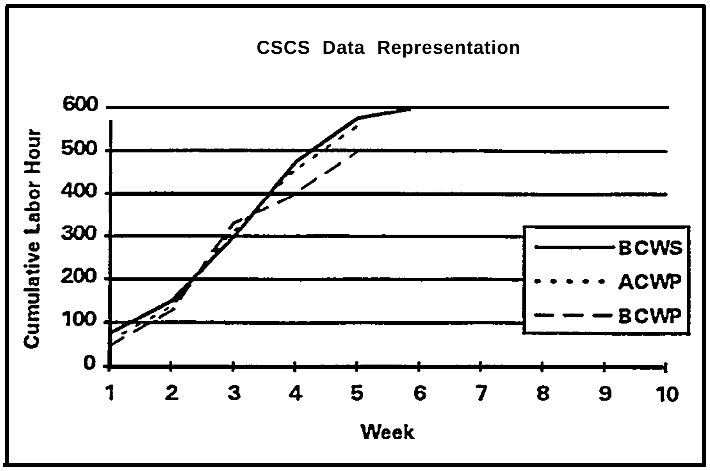
Cost & Schedule Performance

Surface Preparation

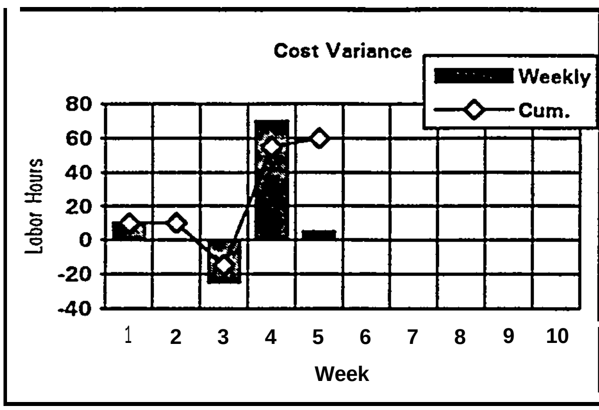
	Hours	% of Budget
Total Budget	600	
Spent Hours	560	93%
Earned Hours	500	83%
Cost Variance	60	10%
Remaining Budget	40	7%

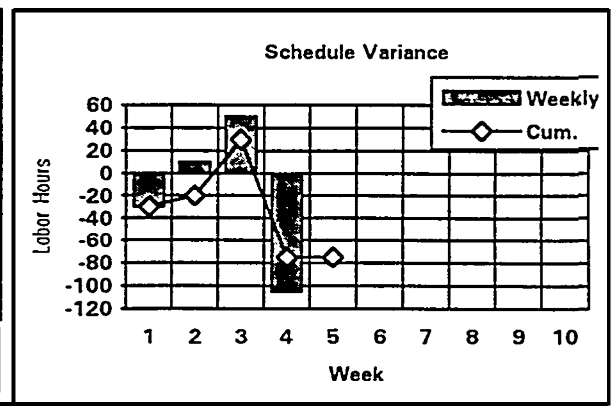
	Hours	% of Scheduled Progress
Scheduled Progress	575	
Spent Hours	560	97%
Earned Hours	500	87%
Schedule Variance	-75	-13%

(+) Cost Variance = Over Target Cost, (-) Cost Variance = Under Target Cost
(+) schedule Variance = Ahead of Schedule, (-) Schedule Variance = Behind Schedule



BCWS = Scheduled Progress
ACWP = Spent Hours
BCWP = Earned Progress





(+) Lost variance = over 1 Target Lost
(-) Cost Variance = Under Target Cost

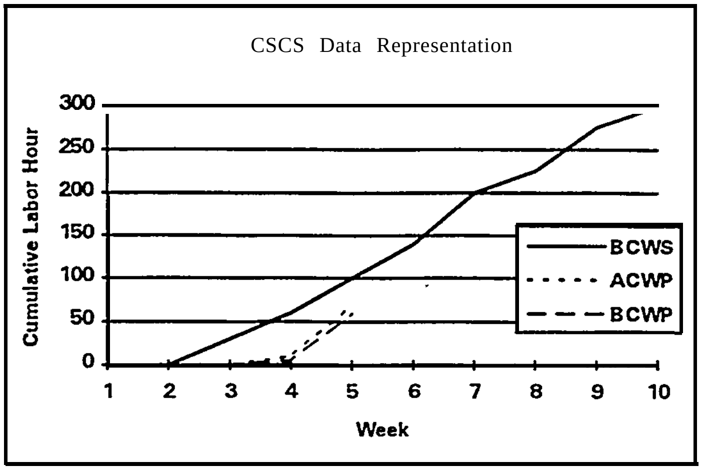
(+) Schedule Variance = Ahead of Schedule
(-) Schedule Variance = Behind Schedule

Surface Coating

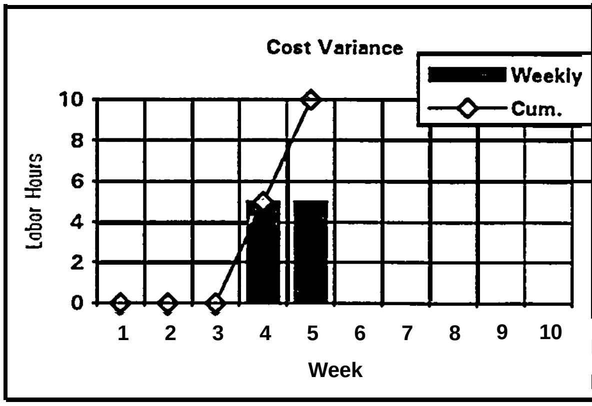
	Hours	% of Budget
Total Budget	300	
Spent Hours	70	23%
Earned Hours	60	20%
Cost Variance	10	3%
Remaining Budget	230	77%

	Hours	I % of Scheduled
Scheduled Progress	100	
Spent Hours	70	70%
Earned Hours	60	60%
Schedule Variance	-40	-40%

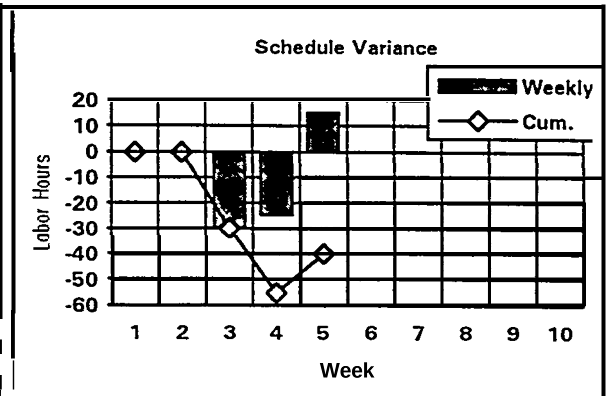
(+) Cost Variance = Over Target Cost, (-) Cost Variance = Under Target Cost
(+) Schedule Variance = Ahead of Schedule, (-) Schedule Variance = Behind Schedule



BCWS = Scheduled Progress
ACWP = Spent Hours
BCWP = Earned Progress



(+) Cost Variance = Over Target Cost
(-) Cost Variance = Under Target Cost



(+) Schedule Variance = Ahead of Schedule
(-) Schedule Variance = Behind Schedule

Productivity

Surface Preparation

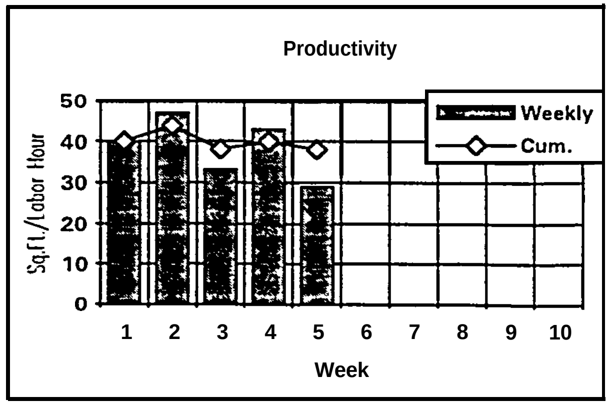
	Sq.Ft.	% Total
Total Sq. Ft.	24000	
Scheduled to Date	22900	95%
Complete	21000	88%
Remaining	3000	12%

	Sq.Ft.	% of Scheduled
Scheduled to Date	22900	
Complete	21000	92%
Output Variance	-1900	-8%

(+) Output Variance = Ahead of Schedule, (-) Output Variance = Behind Schedule

Target Productivity = 39 Sq.Ft./Hour
Productivity to Date = 38 Sq.Ft./Hour
Productivity to Meet Budget =75 Sq.Ft./Hour

Projected Labor at Present Productivity = 79 Hours
Projected Cost Savings =-39 Hours



Surface Coating

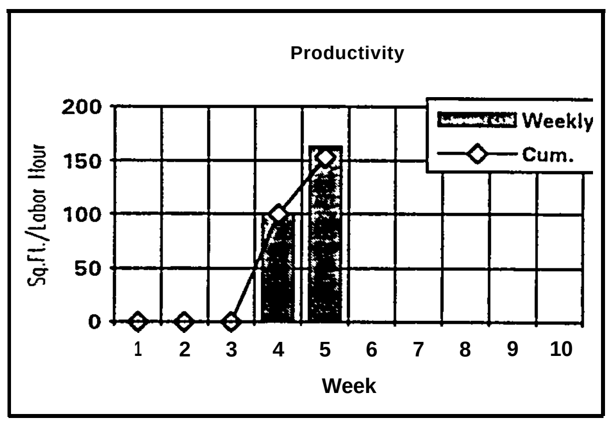
	Sq.Ft.	% Total
Total sq. Ft.	48000	
Scheduled to Date	16000	33%
Complete	10800	23%
Remaining	37200	77%

	Sq.Ft.	% of Scheduled
Scheduled to Date	16000	
Complete	10800	68%
Output Variance	-5200	-32%

(+) Output Variance = Ahead of Schedule, (-) Output Variance = Behind Schwlule

Target Productivity = 160 Sq.Ft./Hour
Productivity to Date = 154 Sq.Ft./Hour
Productivity to Meet Budget = 162 Sq.Ft./Hour

Projected Labor at Present Productivity = 242 Hours
Projected Cost Savings = -12 Hours



Rework

Surface Preparation

	Hours	%
Spent Hours	560	
Rework Hours	8	1%

Surface Coating

	Hours	%
Spent Hours	70	
Rework Hours	4	6%

Quality

Surface Coating Thickness (MILS)

Area (No. Coats)	Target	Mean	Low	High	3 StDev
Void 1 (2)	10	8.73	4.26	13.36	6.35
Void 2 (1)	5	4.61	1.55	9.67	4.55
Void 2 (2)	10	7.39	3.56	15.38	7.64
port Ballast Tank (1)	5	3.63	1.34	6.19	3.30
Stbd Ballast Tank (1)	5	4.22	0.97	13.81	7.06
Lazarette (1)	5	4.73	0.35	11.26	5.86

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